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Assessment of Headlamp Glare and Potential Countermeasures

Survey of Advanced Front Lighting System (AFS) Research and Technology

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16. Abstract

The goal of advanced front lighting systems (AFS) is to actively control headlamp beam patterns to meet the dynamic requirements of changing roadway geometries and visibility conditions. AFS is being rapidly introduced worldwide due to its attractive styling aspects and potential safety benefits. However, before AFS becomes more aggressively implemented, it is necessary to better understand the impacts of AFS on drivers, other vehicles, and pedestrians. To achieve this understanding, this survey investigated comments on AFS from the NHTSA database (Docket 13957), reviewed relevant literature, and held a phone conference with automobile and headlamp manufacturers for industry feedback. The detailed results of the survey are described in this report.

This survey led to a general conclusion that, although a significant number of studies on AFS have been done, due to inconsistency in metrics used and lack of information on experimental procedure and scenarios, further research is still needed to quantify the effectiveness of AFS. In order to evaluate AFS technology, it is important to first identify the appropriate visibility, glare, and safety metrics and test methods. Second, based on these common metrics and test methods, examine the effectiveness of AFS compared to other vehicle forward lighting systems. Based on these findings, two tasks are proposed as future NHTSA research: (1) identify appropriate metrics, performance measures, and test scenarios for AFS; and (2) develop an AFS prototype for evaluation.

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Section 1: Executive Summary

The goal of advanced front lighting systems (AFS) is to actively control headlamp beam patterns to meet the dynamic requirements of changing roadway geometries and visibility conditions. To identify the current state of knowledge regarding AFS, the Lighting Research Center (LRC) surveyed comments on AFS from the National Highway Traffic Safety Administration (NHTSA) database (Docket 13957), reviewed relevant literature, and held a phone conference with automobile and headlamp manufacturers for industry feedback. The following summary gives a brief overview of these activities and presents suggestions for future research.

Survey of Docket 13957

The LRC reviewed all comments on Docket 13957 and summarized the responses to the questions asked, both from individual drivers and vehicle lighting manufacturers. Unfortunately, responses from drivers provided little useful information. However, the fact that most driver respondents complained of glare from standard high intensity discharge (HID) lamps implies that it is important to reduce glare through the use of AFS.

Manufacturers' responses, based on results from several studies, suggest that AFS would provide positive overall experiences to drivers, oncoming drivers, and pedestrians. Manufacturers also stated that AFS will improve drivers' visibility and will not increase glare to oncoming vehicles.

Literature review

Many studies evaluated several types of AFS functionality by using various evaluation methods. Unfortunately, reports on these studies do not generally supply enough information, such as light levels, specific beam distributions, and experimental procedures. Additionally, the majority of these studies did not use common performance metrics that have been proven to be related to traffic safety. These factors make it difficult to reproduce the studies (and thus, the results), generalize the findings to other conditions, and ultimately determine the effectiveness of AFS. The overall conclusion of this review is that further research is needed to determine useful metrics for evaluating and comparing AFS systems.

Regardless of the limitations mentioned, all current research on AFS was reviewed and summarized to better understand the current status of AFS.

Specific issues examined in this study

1. Most AFS functions are reported in recent publications to increase drivers' visibility and reduce glare to oncoming vehicles in certain traffic scenarios. The effect of these AFS functions on traffic safety is not yet known.
2. It is not appropriate to generally apply the results of studies in Europe and Japan to headlamps in North America. Differences in headlamp beam patterns between the United States and other countries, as well as differences in driving scenarios, are likely to affect experimental results.
3. Target detection tests, illuminance calculations, and subjective evaluations are normally used for visibility evaluations. Illuminance and veiling luminance at a driver's eye are also used to

evaluate discomfort glare and disability glare. Subjective evaluations using the de Boer rating scale is the most common form of discomfort glare evaluation.

4. Only simplified scenarios are used in recent AFS studies, including straight roads, single curves, and S-curves with different curvatures.
5. To extend those simple scenarios into more practical roadway situations, various complex scenarios such as hilly roadways and slightly curved highways need to be considered. It is also important to consider headlamp beam patterns for transient periods of time between one AFS category and another.
6. No studies examined behavioral adaptation possibilities from using AFS.

Manufacturer input

The LRC held a phone conference on June 2, 2004 to discuss AFS with automobile and automotive lighting manufacturers. In addition to the LRC, eight organizations participated in the meeting: Ford, General Motors, General Electric, Guide, Hella, OSRAM SYLVANIA, Philips, and Visteon. Two goals were accomplished with this discussion: Input was received from each participating organization about their vision of AFS in the near and far term, and potential gaps in knowledge on AFS research and implications were identified.

Research needs

This survey found significant conflicts in evaluation of AFS performance among existing studies. However, it is difficult to identify the cause of such conflicts, since metrics and evaluation methods used in these studies often differ from each other. It is important to establish common metrics that will allow for consistent evaluation of the effects of AFS on drivers' performance and safety. Based on this finding, the two tasks should be performed in parallel: (1) identify appropriate metrics for AFS; and (2) develop an AFS prototype.

1. Identify metrics for AFS
    - Identify metrics and criteria so as to consistently and meaningfully compare the effects of AFS functionality on human performance, including visibility, glare, and satisfaction, under various scenarios.
    - Calculate illuminance/luminance distributions of AFS functions and evaluate their effects using the developed metrics and criteria.
    - Tie the metrics and criteria to driver behavior (i.e. 100-car naturalistic study) in order to determine the potential consequences of AFS on traffic safety.
2. Develop an AFS prototype
    - Develop a prototype to independently develop and evaluate AFS functionality. This prototype should be mountable to a vehicle and composed of actuators, sensors, and multi-functional headlamps.
    - Conduct human performance evaluation studies using the developed AFS prototype. These studies should prioritize:
        - Bending beam (individually examine the luminous intensity distribution and swiveling algorithm)
        - Dimming under high ambient illumination to reduce glare (town beam)
        - Other functions such as a motorway beam and an adverse weather beam

Section 2: Introduction

The goal of Advanced (or Adaptive) Forward (or Front) Lighting Systems (AFS) is to actively control headlamp beam patterns to meet the dynamic requirements of changing roadway geometries and visibility conditions. In the past, vehicle forward lighting innovations have been limited due to the available technology. Recent advances in lamps, reflectors, actuators, sensors, and controller technologies now allow a variety of variable beam patterns to be introduced. Currently, advanced front lighting systems are categorized by beam "type." These types are: bending beam, town beam, motorway beam, and adverse weather beam (Figure 2.1).

The bending beam is forward lighting with an automatic directional control that turns light into road bends in order to direct the available light where it is needed. The town beam is designed for use in towns and urban areas and has a symmetrical cutoff, wide throw, and homogeneity across the entire area of illumination. The motorway beam is for high speed driving and has forward lighting with a symmetrical, long-throw, and narrow-width distribution to provide the driver with the greatest range of vision while minimizing glare to oncoming vehicles. The adverse weather beam is designed for use in rain, fog, and snow. Manufacturers have proposed that one of solution for adverse weather is forward lighting with high intensity light at the outward edge of the road and low intensity light in the immediate frontal zone.

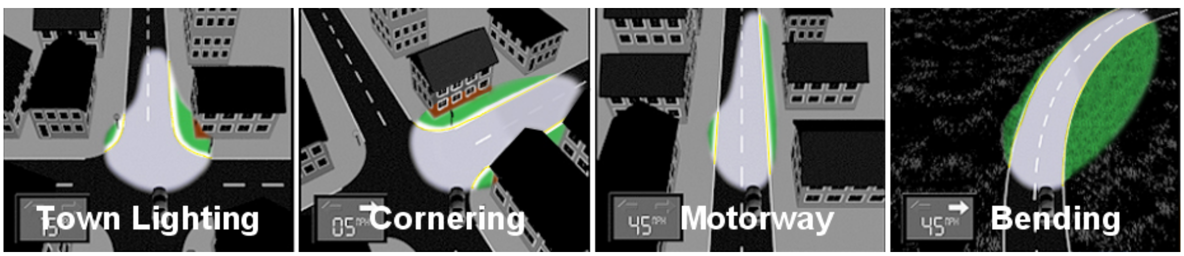

Figure 2.1. Proposed AFS beam patterns (from http://visteon.wieck.com/image_database).

2.1. History of AFS

The earliest practical model of AFS was incorporated in 1948 in an American car, the Tucker Torpedo (Hamm, 2002). The car was equipped with three headlamps; the central one was synchronized with the turning angle of the wheels (Figure 2.2). Only 51 units were made before the company folded. The second attempt was made by Citroen in Europe in the 1950s, and again the headlamps were swiveled in combination with the steering wheel. Due to legal restrictions, this functionality was applied only to high beams, and the low probability of AFS usage opportunities during high beam operation did not encourage other manufacturers to follow this unique approach. In the early 1960s, a similar concept to the current AFS was proposed by Balder (1962). Unfortunately, the technologies of those days could not make the concept turn into a reality. Missing technologies were the optical accuracy in designing lamp/reflector systems and the stability of headlamp leveling mechanics (Westermann, 2002). Then, about 20 years later, the Eureka Project began.

Figure 2.2. Tucker Torpedo in 1948 (copy right: Smithsonian Institute).

2.2. Outline of the Eureka Project

Eureka Project EU 1403 began in 1993. Countries and manufacturers (BMW, Bosch, Daimler-Benz, Fiat, Ford, Hella, Magneti-Marelli, Opel, Osram, Philips, PSA, Renault, Valeo, Volkswagen, Volvo, and ZKW) participating in the Eureka Project began defining requirements for advanced headlamp systems. There were three phases in the Eureka Project. The first phase was a marketing study to find problems with conventional headlamps and determine drivers' needs. The results of the marketing study prioritized AFS functions; including dynamic glare, and the influence of shape, area, and partition of headlamps on glare, as well as on vehicle appearance to other vehicles. In the second phase, initial plans called for the exploration of reflectance of wet and dry road surfaces, reflectance of pedestrians, and locations of road signs and pedestrians. However, due to budget limitations, the focus was restricted to glare and appearance issues only. AFS prototypes were developed and tested by a field evaluation. In the third phase, based on the results of the first and second phases, the Eureka Project drafted AFS regulations including: (1) development of a new AFS regulation (TRANS/WP.29/GRE/2002/18 and 19); and (2) amendments for mounting and operating regulations of AFS systems in ECE regulation No. 48 (TRANS/WP.29/GRE/2002/20).

Based on the accomplishments of the Eureka Project, the above described ECE regulations have been modified. AFS will be officially released in Europe in two stages. The first stage, approved in 2003, allows swiveling (or bending) of the low beam function. The second stage is forecast for approval in 2005. This could include situation-related functions, such as motorway and town lighting.

2.3. Objectives and procedure of this study

Before AFS becomes more aggressively implemented in the United States, it is important to understand the impacts of AFS on drivers, other vehicles, and pedestrians. The two main goals of this study are to identify the current state of AFS development and application, and to examine the supportive research on AFS. The following are the detailed objectives of this study:

1. Identify and estimate the potential safety benefits of different AFS applications.
2. Determine applications of European AFS research to North American roadways and beam patterns.
3. Identify and assess the validity of methods that have been used to evaluate AFS in terms of driver safety-related performance and acceptance.
4. Identify and categorize driving scenarios that have been used to study driver performance using AFS.
5. Identify additional scenarios that need to be studied to provide a more complete assessment of AFS capabilities and limitations.
6. Identify any studies that have examined behavioral adaptation possibilities from using AFS.
7. Recommend research studies needed to determine what AFS performance requirements would improve safety and minimize unnecessary glare.

2.4. Summary of findings

Many studies evaluated several types of AFS by using various evaluation methods. Unfortunately, reports on these studies do not generally supply enough information, such as light levels, specific beam distributions, and experimental procedures. Additionally, the majority of these studies did not use common performance metrics that have been proven to be related to traffic safety. These factors make it difficult to reproduce the studies (and thus, the results), generalize the findings to other conditions, and ultimately determine the effectiveness of AFS. The overall conclusion of this review is that further research is needed to determine useful metrics for evaluating and comparing AFS systems.

On the basis of the facts, this survey reached the following conclusions for each objective:

1. Various types of AFS functions including bending beam, town beam, and motorway beam may increase drivers' visibility and reduce glare to oncoming vehicles in certain traffic scenarios. However, it is important to establish robust metrics and criteria to quantify the effect of each AFS function and possibly relate it to traffic safety.
2. It is not appropriate to assume that the results of studies in Europe and Japan apply to headlamps in North America. Differences in headlamp beam patterns, traffic patterns, and roadway geometries are likely to produce conflicts in experimental results between North America and other countries, especially with regard to glare. This assumption is based on conflicts found in similar studies.
3. Several methods are commonly used to evaluate visibility and glare. To evaluate drivers' forward visibility, target detection tests, illuminance calculations, and subjective evaluations are typically used. Target detection tests and illuminance calculations typically provide more objective outcomes than subjective opinions. Although eye fixations were used in several studies, there is little agreement on how to interpret those data. It is not appropriate to use eye fixations as a metric of AFS performance until it becomes clearer how eye fixation points are related to driving safety and comfort.

   Subjective evaluation using the de Boer rating scale is the most common form of discomfort glare evaluation. As a simple measure of discomfort glare, illuminance at a driver's eye, or so-called glare illuminances, is also used. To evaluate disability glare, veiling luminance is used. While there is agreement on the calculation of disability glare in terms of veiling luminance, it is not yet clear if the glare illuminance corresponds to the discomfort glare sensation. It also is not clear how low glare illuminance should be in order to prevent drivers from feeling discomfort. It is first important to identify the validity of glare illuminance as a discomfort glare index and establish the criteria for various scenarios.

4. Scenarios used in recent AFS studies were straight roads, single curves and S-curves with different curvatures, well-lit areas, motorways, and inclement weather conditions.
5. To extend those scenarios into more practical roadway situations, more complex scenarios such as hilly winding roadways and slightly curved highways need to be considered in conjunction with different AFS functions. It is also important to develop appropriate headlamp beam patterns for transient periods of time between one AFS functional category and another; improper transient adaptation caused by poorly engineered transition algorithms may result in glare and lower visibility.

This survey found significant conflicts in evaluation of AFS performance among existing studies. However, it is difficult to identify the cause of such conflicts, since metrics and evaluation methods used in these studies are often different from each other. It is important to establish common metrics that will allow for consistent evaluation of the effects of AFS on drivers' performance and safety. Based on this finding, the two tasks should be performed in parallel: (1) identify appropriate metrics for AFS; and (2) develop an AFS prototype.

Identify metrics for AFS

- Identify metrics and criteria so as to consistently and meaningfully compare the effects of AFS functionality on human performance, including visibility, glare, and satisfaction, under various scenarios.
- Calculate illuminance/luminance distributions of AFS functions and evaluate their effects using the developed metrics and criteria.
- Tie the metrics and criteria to driver behavior (i.e. 100-car naturalistic study) in order to determine the potential consequences of AFS on traffic safety.

Develop an AFS prototype

- Develop a prototype to independently develop and evaluate AFS functionality. This prototype should be mountable to a vehicle and composed of actuators, sensors, and multi-functional headlamps.
- Conduct human performance evaluation studies using the developed AFS prototype. These studies should prioritize:
  - Bending beam (individually examine the luminous intensity distribution and swiveling algorithm)
  - Dimming under high ambient illumination to reduce glare (town beam)
  - Other functions such as a motorway beam and an adverse weather beam

Section 3: Manufacturer Input

3.1. Introduction

The LRC held a phone conference on June 2, 2004 to discuss AFS with automobile and automotive lighting manufacturers. In addition to the LRC, eight organizations participated in the meeting: Ford, General Motors, General Electric, Guide, Hella, OSRAM SYLVANIA, Philips, and Visteon. There were two goals for this discussion: to get input from each participating organization about their vision of AFS in the near and far term, and to try to fill in potential gaps in our knowledge on AFS research and implications. The following section summarizes this meeting by outlining the responses to selected questions asked of the group.

It should be noted here that this summary (Section 3) does not necessarily reflect the opinions of NHSTA or the LRC, but report participants statements in the meeting.

In general, manufacturers were eager to discuss AFS functionalities now being introduced. For example, many stated that the bending beam functionality would most likely be introduced first on high-end vehicles in the United States, similar to the introduction of HID headlamp systems, but is already being introduced in Europe on mid-range vehicles. However, due to the confidentiality of product development, manufacturers did not speculate on the future of AFS or discuss any research findings that were not already published.

3.2. Points of discussion and responses

What are your organization's short and long-term visions of AFS?

- The integration speed of AFS into the market depends on the region. Europe will lead the way with lower-middle class market segments and North America will probably start with luxury vehicles. In North America, bending beams are probably for luxury cars only; it will take awhile for bending beams to move down the market, similar to the introduction of HID. In Europe, AFS functions have been implemented on five middle class cars already. Japan has taken similar action.
- AFS is dependent on light source development. AFS demands more light from sources, so HID and higher luminance sources are preferred. There will be innovation in light sources with AFS. All the impacts of AFS on source performance are not known yet. For instance, frequent switching could affect source lifetime performance.
- What other functions will get packaged in AFS vehicles?
    - There are two considerations: safety impact and customer-perceived benefit. The driver can literally see the benefits of some AFS functions. In the absence of publicized proven safety benefits, the inclusion of additional safety functions that cannot be perceived by the driver will be minimized.
    - Different AFS functions will be introduced one at a time depending on car class; every function is not needed at once.
    - The objective for AFS is clearly based on performance, not affordability. Affordability for AFS is not pursued in the same way as it is for other safety measures, such as airbags, ABS brakes, and passive restraints.
    - One main issue is communication to the system: What types of signals and protocols should be used? Intra-vehicle communication systems are not standardized and

different companies have different philosophies as to which functions should have priority; there will be compatibility issues.

Are other beam functionalities for AFS currently being developed for production besides bending beams?

- Motorway would be first, probably. It is simple to adjust the beam for a motorway in comparison to other beam functionalities. (This beam will be different from traditional high beams by providing a longer, narrower throw, and by activating with vehicle acceleration.)
- However, the answer to this question depends on the approach for achieving AFS. One concept for creating AFS functionality is to generate beam distributions with one module and a movable shutter; this approach could imply that all defined AFS functions (bending, town, motorway, and adverse weather) could be introduced next, at the same time.

What are the barriers preventing AFS from being implemented—regulations, sensors, failsafe technologies?

- The exact barriers are difficult to predict at this point because the technology is still so new. Standardization is needed but not at the cost of innovation.
- Cost is one barrier as is customer perceived benefit (would a driver be willing to pay extra for AFS?).
- Regulation: the number of headlamp sources is restricted to two, there are conflicts among state regulations, and the state of government knowledge regarding AFS is poor.
- Sensors: Sensor technology is available off-the-shelf for integration with AFS systems. Velocity, acceleration, steering, and ambient light level sensors can all be used to assist automatic control and operation of AFS functions. However, the costs of these technologies can become an issue. There is the possibility of sharing sensor technology for AFS with other vehicle functions, which would help offset the costs. The question then arises about in-vehicle communication priorities. This is a usual consideration; however, lighting has never been involved before.

Visual performance questions:

Do bending beams cause more glare than conventional forward headlamps? What criteria do you use to identify the optimal bending beam system?

- There were no stated opinions about whether bending beams result in more glare.
- Good bending beam criteria:
    - Bending beam designs have narrowed down among manufacturers; (it is this participant's position that) glare is not seen as being noticeably different from case to case. What is a good system? Customers vary. Elderly drivers, sports car drivers, etc. have different requirements; people won't agree on what is "the best."
    - Studies must be conducted for each specific system to evaluate issues such as safety factor, comfort, and marketing. This would be required for every system.
    - These studies are done but not published.
    - The transitional movement and degree of asymmetry is currently unique to each vehicle.

What research do you feel needs to be done?

- Highway beams versus high beams. How wide should a beam be? Human factors research is needed to determine the importance of peripheral vision.
- The average statistical driver needs to be defined.
- Local conditions: What are the differences in headlamp performance and visibility based on location?

Section 4: NHTSA Docket Summary

NHTSA issued Docket 13957, Glare from Headlamps and Other Front-Mounted Lamps: Adaptive Frontal-Lighting Systems Federal Motor Vehicle Safety Standard No. 108; Lamps, Reflective Devices, and Associated Equipment. The purpose of this docket was to elicit comments from the automobile industry, as well as individual drivers, to assess AFS development and its effect on the risk of a crash.

This section summarizes the response received to this docket. The responses are broken into two sections: one for the driving public, and one for manufacturers and industry.

DRIVERS
Sixty-six responses were generated from drivers, driving safety advocacy organizations, and academics. The comments from individual drivers numbered 62, the majority of which were general complaints toward standard HID technology and are more applicable to NHTSA Docket 8885. Only three responses were specific to the questions listed, and these are summarized below for each driver question. However, in general, there were three main points from these responses:

- HID headlamps cause glare and should be regulated, restricted, or banned.
- Glare from high-mounted halogen headlights is comparable to glare from HID headlamps, so headlamp mounting height should be regulated, restricted or standardized.
- Fog lights are misaimed and used unnecessarily, causing glare, so fog light use should be restricted, regulated, or banned, and switches should be instituted so users must actively turn them on.

QUESTIONS FOR DRIVERS
Question 1:
Do you have problems seeing around curves because of the limitations of the headlamps on the vehicles that you drive, or because of the glare from an approaching vehicle? Please describe the problems, including road, ambient lighting, and weather conditions.
Responses to this question were mixed, with approximately equal numbers for both yes and no. One response indicated that sharp corners limit forward visibility from headlights, and another stated that oncoming glare is more detrimental. Left-hand turn visibility limitations were emphasized.

Question 2:
Is the glare that you described above worse than the glare from vehicles approaching on straight roads? Is this because the light is brighter or because it is longer lasting?
Responses to this question were mixed, with approximately equal numbers for both yes and no. One response indicated that glare during turns is worse because it is brief and intermittent, and another stated that glare on straight roads is worse because it is longer-lasting and continuous.

Question 3:
Under what nighttime driving conditions have you thought you needed extra headlamp illumination to help you see the road, signs, or objects: when turning at intersections, when

driving on curved roads, at intersections, driving in rain, when driving in fog, when driving on interstate highways, driving in cities?
Several driving situations that could use additional illumination were named: left-hand turns at intersections, highways, curvy roads, and adverse weather conditions such as fog and rain.

Question 4:
Under what nighttime driving conditions have you thought that the oncoming headlights seemed more glaring than usual: on right-hand curves, on left-hand curves, on high-speed roads, at intersections in cities, on hilly roads?
Oncoming lights are perceived by drivers as producing more glare on right hand curves, and particularly on hilly roads and high-speed, straight roads.

Question 5:
What types of objects are most difficult for you to see when driving at night: pedestrians, lane markings, street signs, stop signs, overhead guide signs, debris on road, animals, etc.?
Animals, pedestrians, and lane markings are all difficult for drivers to see, and most importantly, road debris.

Question 6:
For a "bending beam" AFS that added more illumination to the right on right-hand curves and to the left on left-hand curves, what aspects of lamp design concern you the most: that lamp failure might reduce visibility; that added light on left-hand curves would increase glare to oncoming drivers; that the motion of the lights would be annoying; that the added light would not be bright enough to significantly increase the visibility distance?
Drivers are most concerned with the potential increase in glare; failure modes and reliability are also a concern.

Question 7:
If a headlighting rating were available for new vehicles in the same manner as crashworthiness and rollover star ratings, would you use these headlighting ratings in the decisions that lead to your purchase of a new vehicle? On a scale of 1 to 10 with 1 being of little value and 10 being extremely important, how might you rate the importance of the headlamp rating, if available, to your purchase decision for a new vehicle?
All drivers indicated that a headlighting rating would be useful. One indicated that it would range from 8 to 10 on a scale of importance, and one said it would be a 6.

INDUSTRY
Industry respondents to Docket 13957 (manufacturers and organizations representing manufacturers) totaled 18. Many of the manufacturers referred to major published studies, with most of the emphasis placed on the Japan Automobile Research Institute's (JARI) 2002 report to the Japanese Automobile Manufacturers Association (JARI, 2002) and the European AFS study referred to as the Eureka Project. Other references were made to the UMTRI reports on bending beams and SAE papers. None presented data from their internal research, but many of them reported observations and findings. In general, there were several main points from the industry response:

1. The driver is provided with increased visibility.
2. The oncoming driver experiences no more glare than from typical headlighting systems (halogen and HID) in use today.
3. AFS provides a net positive factor to the driving experience for everyone on the road.
4. AFS technology is feasible and useful but may be expensive initially.
5. Manufacturers expressed an interest in addressing the needs and concerns of the public and working with NHTSA in tangible ways to achieve this goal.

QUESTIONS FOR INDUSTRY

Question 8:

Have manufacturers evaluated prototype AFS-equipped vehicles at night to determine whether changes in the intensity and direction of illumination may cause misdirection of any driver's gaze toward the newly lighted or intensified area, or away from objects that are still important for driving safety?

All who responded to this question stated that misdirection is not a problem; the driver's gaze is correctly directed. Two main studies were referred to, namely the JARI report and the Eureka study. The JARI study shows that the driver's fixation point precedes the beam distribution of the AFS system on a curve; in effect, the AFS headlamps were not quick enough to match the line of the driver's sight, but followed it to illuminate the region the driver was looking at. The Eureka study shows that the eye is directed to appropriate areas on the road, rather than misdirected, and visibility is improved. One manufacturer (Koito) evaluated its own system and stated that its results support the findings of these studies.

Question 9:

Do moving beams (from bending beam or the increase or decrease in intensity) either increase or decrease the level of driver fatigue compared to non-AFS lighting?

All manufacturers stated that there are no known studies of fatigue for AFS systems. One pointed out that there is no negative information related to usage of cornering lamps. Reference was made to two technical papers, SAE 2001-01-0299 and UMTRI 2002-3, which show that better road illumination increases subjective evaluations of comfort, and it is suggested that comfort can be equated with driver fatigue.

Question 10:

Have vehicle manufacturers evaluated prototype AFS-equipped vehicles at night as occupants of other vehicles to evaluate the potential glare from AFS? If so, please describe the evaluation and the results. Are there other assessment methods used to assess the glare from the AFS before vehicle manufacturers commit to a particular AFS design?

Most manufacturers agree that AFS systems show slight or no improvement in glare for the oncoming driver overall, with minor exceptions being made for left-hand turns. Curve direction affects glare, with less glare being produced in right-hand turns and left-hand turns resulting in more glare. Therefore, the overall glare produced is roughly equivalent to that of static headlamps. One manufacturer (Stanley) stated that calculations and simulations indicate less glare on curves from AFS systems than static headlamps, presumably because the lamps do not face the same swivel angle, and referred NHTSA to SAE technical paper #2001-01-0854. Visteon has had a fleet of AFS-equipped cars on public roads for two years without a single complaint of glare or dimming request from oncoming drivers. The JARI study found that AFS systems had glare equivalent to or less than that of conventional headlamps in all scenarios tested, except for the left-hand turn. Several references were made to a Virginia Tech Transportation Institute (VTTI) study that supports this finding, showing that bending beam systems produce less glare in all scenarios tested except for an 80 m left-hand turn. Finally, GM submitted a discomfort glare study report that shows an improvement in glare rating for the AFS system in seven of eight road geometries; the exception was the 80 m left-hand turn. All of these increases are regarded as minimal by the manufacturers.

Question 11:
What assessment is made of potential glare from AFS at points in the beam pattern that are currently unregulated?
Most manufacturers feel that the standards already in place, SAE J2591 and ECE 48, do an adequate job of specifying beam pattern requirements. European beam patterns are fully regulated, and swivel angle is restricted by ECE 48. Headlamp leveling is the only factor not regulated and it was suggested for incorporation. One manufacturer (Visteon) pointed out that the sensitive region for glare is a rectangular area bounded by ½U from 1½ L to 1L, and 1U from 1½L to L.[1] The points within this region are regulated by the boundary value standard.

Question 12:
Are there any current lamp or vehicle manufacturer corporate design guidelines for AFS that deal with unregulated points in the beam pattern?
Most manufacturers did not comment on this question (refer to their response for question 11) or state that there are no guidelines. Several conceded that they do have corporate design guidelines, but that they are customer or visibility driven.

Question 13:
To what extent do lamp and vehicle manufacturers consider the reports and work by the Society of Automotive Engineers and other non-governmental bodies on the subject of glare in designing the performance of AFS on their vehicles?
In answering this question, manufacturers are asked to provide a list of the reports, papers and data that they found useful in establishing design guidelines. Most manufacturers profess to be working in accordance with ECE and SAE regulations and are closely involved with ongoing research conducted by the International Electrotechnical Commission (IEC), Group de Travail Bruxelles (GTB), SAE, Transportation Lighting Alliance (TLA), UMTRI, and the Eureka Project. Cited documents include:

- ECE R98
- ECE R112
- SAE J565
- SAE J2591
- UMTRI 92-14, 92-16, 93-10, 94-29, 97-7, 2000-41, 2001-20, 2001-33, 2002-20

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[1] These are angular coordinates. In Visteon's wording, "1/2U" is 0.5° above horizontal center, "1U" is 1° above horizontal center, "1L" is 1° left of center, and "11/2L" is 1.5° left of center.

Question 14:
While we are aware of many studies to demonstrate and promote the efficacy of AFS, we are not aware of a single study that has been done on the effects on other drivers facing AFS-equipped vehicles or on drivers using AFS-equipped vehicles.
NHTSA was referred to the JAMA Research on AFS report, March 2002, and GM's study submitted in the docket. Valeo referred to various AFS demos in Europe. Additional studies were referred to in the following documents:

- UMTRI 2002-2
- SAE 970646
- Cieler et al. (2002) Effects of the Visteon advanced front lighting system (AFS) on driver behavior and driving safety. (Final report for Project No. 947-724001). TUV Institute for Traffic Safety.

Question 15:
Has glare been studied specifically for younger and older drivers facing or preceding the various modes of AFS operation on vehicles?
Age-related effects of glare are well-known and documented in DOTHS808 452. Manufacturers stated that this effect is not specific to AFS, and that they have not noticed anything unusual in age-effects. The UMTRI 2002-2 study found that younger subjects (early to mid twenties) were more sensitive to glare on the left, while older subjects (aged 55 to 65) were more sensitive to glare on the right, but these findings are questionable due to non-smooth swivel movement. In the VTTI study, all subjects were between 55 and 65 years old, and this study found that AFS improved glare.

Question 16:
Has diminished recognition of presence, or the perception of distance or closure rate to an oncoming AFS vehicle, ever been studied?
UMTRI 2002-2 shows that there is no significant difference in appearance between AFS headlights and static systems. In addition, this topic has been studied in detail by Professor Soardo of the Instituto Elettrotecnico Nazionale Galileo Ferraris (IENGF) in Milan, Italy for the Eureka Project; the findings of this study led to ECE regulation 48 and the minimum separation of function requirement in SAE J2591.

Question 17:
What fail-safe features for each possible mode of AFS operation have been developed and studied that will prevent glare to oncoming and preceding drivers?
SAE J2591 and ECE 48 prescribe regulations for malfunction indicators for the driver. A minor concern is the wrong horizontal swivel position, whereas the wrong vertical level is a major concern. Manufacturers are investigating a variety of fail-safe modes, most of which involve either returning the beam to a neutral position and/or tilting the beam downward. Toyota's model uses two motors, one for the horizontal swivel and one for vertical aim. In failure mode, horizontal repositioning is attempted first, and if this is broken, the vertical level is tilted down to reduce glare. GENTEX's system has only two modes, with automatic low beam and high beam switching, so its failure mode is the low beam setting. Stanley's system consists of an automatic communication between the swiveling actuator, AFS ECU, and leveling ECU. Koito and North

American Lighting (NAL) are investigating fail-safe operations for the failures listed in Table 4.1.

Table 4.1. Failures and corresponding fail-safe modes
(after NAL's response to Question #17 of NHTSA Docket 13957).

Failure	Fail-safe mode
Swiveling actuator ceases to function properly	Attempt to return lamp and hold at initial position
	Leveling aims lamp down to reduce glare potential
Communication signal interrupted between swivel and ECU module	Return lamp and hold at initial position after failure detection
ECU ceases to function properly	Return lamp and hold at initial position after failure detection

Question 18:
What fail-safe features for each possible mode of AFS operation have been developed and studied that will prevent no greater risk to the driver using it than when non-AFS headlighting fails?
Most manufacturers failed to see the point of this question, since the failure mode for conventional headlamps is complete darkness. How could anything AFS does be any worse?

Question 19:
What studies have been done to demonstrate whether AFS adds safety value? What value is that and how was it measured?
"Safety" has not been studied or proven; this requires years of statistical data that is not available to anyone currently. Therefore, all assumptions are visibility-based. Simulations and prototype lamp testing all show more light on the road as an end-result of the AFS system, which results in better visibility for the driver. One manufacturer, for example, showed that detection distance improves 250%.
Documents referred to showing these results are:

- UMTRI 99-21, 2001-20
- SAE 2001-01-0299, 2001-01-0854, 2002-01-0526
- JAMA/JARI report

Question 20:
What are the anticipated incremental costs of adding the various designs of AFS features to halogen headlighting systems?
Many manufacturers did not comment on this question; all manufacturers that did respond agreed that the cost would vary, depending on the options included and vehicle integration. One manufacturer responded that the cost would be comparable to what drivers are willing to pay, which is currently between $50 and $500. NAL stated that a swivel halogen low beam system would cost twice the price of a base halogen system, plus the cost of any additional electronics and sensors, and that a bending lamp would cost approximately what a fog light costs.

Question 21:
What are the anticipated incremental costs of adding the various designs of AFS features to high intensity discharge headlighting systems?
Many manufacturers did not comment on this question; all manufacturers that did respond agreed that the cost will vary, depending on the options included and vehicle integration. One manufacturer stated that the cost is independent of the light source used. Another hypothesized that since most HIDs (and perhaps soon all) already come equipped with automatic leveling, the additional replacement cost for AFS would be less for HID headlamps than for halogen.

Question 22:
What are the anticipated incremental costs of adding the various designs of AFS features to light-emitting diode headlighting systems?
Many manufacturers did not comment on this question; all manufacturers that did respond agreed that the cost will vary, depending on the options included and vehicle integration. Most responded that currently the cost of LED headlamp systems is prohibitive in general, and that the cost of an LED AFS system could not be estimated until LEDs are in common use.

Question 23:
Presumably, the added illumination in curves is intended to reduce the risk of a crash. However, because most crashes are on straight roads (because of the predominance of straight roads), how does the presumed incremental benefit compare to the added cost of AFS? Does the incremental benefit outweigh the potential for additional glare to oncoming or preceding drivers in a curve or intersections or during an AFS failure? Why?
Several manufacturers did not answer this question on the premise that there is not yet enough information. Many did not answer the projected cost questions. There are several points to address here, and the glare issue appears to have dwarfed any responses to the straight-away issue. All manufacturers agree that when functioning well, glare caused by AFS systems is not a problem, and that the failure modes developed will prevent the occurrence of accident-causing glare. So already the potential benefit of AFS systems is expected to be high, with minimal potential for additional glare. One manufacturer (GENTEX) states that its AFS functionality, with automatic high beam control, is most beneficial on straight roads, and that this benefit greatly outweighs the cost. Overall, the benefit/cost ratio is expected to be quite good.

Question 24:
Should AFS designs be incorporated as separate, regulated lighting systems that operate independently of the primary headlighting system?
Fourteen manufacturers answered this question. Five out of 14 (36%) thought AFS should be regulated as a separate extension; two out of 14 (14%) thought it should be regulated together with the primary system under a revised version of FMVSS108; two out of 14 (14%) thought either option was fine; and five out of 14 (36%) thought AFS should not be limited by regulation, period.

Question 25:
Given that known AFS prototype designs are intended to use more headlamp replaceable light sources than currently permitted, should AFS headlamps be limited in total luminous flux?

Thirteen manufacturers answered this question. Ten out of 13 (77%) thought there should be no limitation. Three out of 13 (23%) thought the total flux should be limited, with qualifiers: the limits should be placed on the total flux from the entire fixture, not the light source; the limits should be region-based, such as the total flux in the glare region versus the flux in the foreground; and that studies should be conducted to determine these limits.

Question 26:
Should AFS headlamps have unlimited luminous flux if automatic headlamp leveling and cleaning are incorporated, as currently mandated in Europe for headlamps that have light sources that are rated at 2000 lumens or more?
Thirteen manufacturers answered this question. All agreed that headlamp leveling was of greater importance than headlamp cleaning. Seven out of 13 (54%) thought that headlamp leveling should be mandatory, whereas headlamp cleaning should be optional, without stating clearly that luminous flux should be unlimited under these conditions. Six out of 13 (46%) thought that there should be no limitation on the total flux of an AFS system, citing wet road conditions, photometric requirements already in place, and maximum intensities already specified as justification.

Question 27:
What is the feasibility of reducing the intensity of AFS lamps during low speed, dense traffic, or high ambient illumination conditions?
All manufacturers that addressed this question agreed that this is feasible if the AFS system is tied to sensors and controls. Potential mechanisms for achieving reduced intensity include pulse width modulation, dimming of halogen lamps, and downward tilting of HID lamps, as dimming is difficult for this light source.

Question 28:
Are there requirements in Standard No. 108 that are barriers to the implementation of AFS? If there are barriers, in accordance with the published lighting policy of the agency (see NHTSA Docket 98-4281 at http:lldms.dot.qov/search/document.cfm?documentid-46284&docketid=4281*), what data exist showing safety benefits to justify amending the standard to permit AFS?*
Again, it is difficult for the manufacturers to clearly state "safety" benefits, although the general benefits of improved visual performance for drivers with AFS and reduced glare for opposing drivers are claimed. Specific barriers named in Standard No. 108 include the requirements in 5.7.4, 5.7.5, and 5.7.6, which state specific requirements for the number of light sources, their position, and photometrics. The standard states that no more than two light sources can be used, which is a major hindrance to AFS systems. Additionally, 5.7.5 states that no "individual" adjustments can be made to the reflector or assembly, and 5.7.6.1 requires a "symmetrical effective projected luminous lens area" for the low beam. Several manufacturers expressed that they would like some room here to design asymmetric luminous lens areas with symmetric lens configurations. Finally, they stated that there are aiming restrictions in the standard that prevent the low and high beams from being aimed independently. It is suggested to incorporate the requirements stated in ECE R98 and/or R112.

Question 29:
Should AFS be mandatory? What data exist showing safety benefits to justify amending the standard to require AFS? If AFS should not be mandatory, why not?
Twelve manufacturers answered this question. Twelve out of 12 (100%) agreed that AFS should NOT be made mandatory at this time. Reasons include the premature status of AFS technology, the lack of "real world" and safety data, the variation in customer population (not all people use their car the same way), and finally the cost, which may be quite high initially. They feel that the balance between safety and cost should be market-driven, as it is for other safety measures, rather than mandated by regulation.

Question 30:
Should AFS be permitted as a replacement for non-AFS headlighting systems? If so, why, and what safeguards are necessary beyond that necessary for new OEM installations? If not, why not?
Twelve manufacturers answered this question. One out of 12 (8%) said this question could not be answered without further study because there are too many questions concerning the interface with steering angle, pitch and yaw sensors, etc. Four out of 12 (33%) said no because the vehicle integration in an after-market installation may be too complicated to carry out effectively and reliably. Seven out of 12 (58%) said AFS replacement should be allowed, with the caveats that it may be extremely challenging and expensive, and that the final installation must meet the same requirements and standard compliance as original equipment manufacturer (OEM) systems.

Section 5: AFS Literature Review

5.1 Relevant literature

An extensive literature survey of AFS research and development was conducted as part of this study. Most pertinent published documentation, including scientific studies, review articles, sensor innovations, user acceptance surveys, control technology research, and manufacturer and research-based prototype evaluations, were collected and included in this list. It should be noted that many studies performed on AFS are conducted by manufacturers for system development and are for internal use only, and this research could not be accessed. The available references are given in alphabetical order in Appendix A.

5.2 Reviewed literature and summary

A select subset of the pertinent references relating to AFS development were reviewed and summarized in greater detail. Brief abstracts of these documents can be found, listed alphabetically, in Appendix B.

Regardless of the limitations mentioned, all current research on AFS was reviewed and summarized to better understand the current status of AFS. It should be noted that, unfortunately, many reports on AFS studies do not supply enough information, such as light levels, specific beam distributions, and experimental procedures. Additionally, the majority of these studies did not use common performance metrics that have been correlated to traffic safety. These factors make it difficult to reproduce the studies (and thus, the results), generalize the findings to other conditions, and ultimately determine the effectiveness of AFS.

Regardless of the limitations mentioned, all current research on AFS was reviewed to better understand the current status of AFS. These studies evaluated many aspects of AFS functions including bending beam, town beam, and motorway beam by using various evaluation methods. The following summarize the findings:

Bending beam

Can a bending beam increase traffic safety?

A bending forward lighting beam pattern is one that changes dynamically in response to a vehicle's change in direction with steering. Currently, different bending beam types are proposed—a static bending beam, where additional components are added to the existing beam pattern, and several variations of dynamic bending beams, where the entire beam pattern swivels. Since the bending beam has not been applied to many vehicles, statistical data on how the bending beam contributes to traffic safety are not yet available. However, existing accident data collected by the Federal Highway Administration (FHWA) indirectly suggest that appropriate bending beams have the potential to reduce accidents on curves with relatively small radii. The FHWA data shows that the crash rate increases disproportionately as a curve radius decreases, and that the nighttime crash rate is higher for curve radii smaller than 350 m.

Can a bending beam provide better visibility than standard headlamps?

- Data are inconsistent on this question. However, certain types of bending beams under certain conditions have been shown to increase drivers' visibility.

- In some studies, a static component proved to be more effective than a dynamic component in illuminating curves of small radii and intersections, while a moveable component was necessary to illuminate curves of larger radii.
- In some studies, within an S-curve a standard headlamp system more effectively illuminated the crossover point than any types of bending beams.

Can a bending beam reduce glare to oncoming vehicles?

- One study suggests that a bending beam can be significantly glarier than a standard headlamp system, while another study found a bending beam to be significantly less glary than a standard headlamp system in most cases.
- The conflict might be attributed to differences in headlamp types (i.e., projector or reflector) or cutoff types (i.e., the US SAE or Economic Commission for Europe (ECE) cutoff standard).

In order to definitively answer the question of which provides better visibility and less glare (bending beam or conventional headlamps), a systematic study needs to be conducted with reliable evaluation criteria under various conditions covering wider ranges of headlamp types, cutoff standards, control algorithms, and scenarios. It is also important to consider the lag time.

Town beam

Can dimming forward headlamps minimize glare to oncoming vehicles without impairing drivers' visibility?

A town forward lighting beam pattern is one that becomes shorter and wider in response to high ambient, low speed conditions. A review paper in the 1970s identified the appropriate luminous intensity range for town beams, suggesting it should be higher than 20 cd and lower than 100 cd. However, since this review paper did not show background data describing how those luminous intensity values were identified, it is still necessary to discuss appropriate luminous intensity distribution of town beams and conduct field studies on real roadways by using town beam prototypes. Recent controlled field studies conducted by the LRC have provided positive answers to this question. The first study proved that it is possible to dim forward headlamps without impairing drivers' forward visibility in lit areas. The second study showed that oncoming headlamp glare impairs drivers' forward visibility in such a way that detection distance was 20 m longer with oncoming headlamp glare than without glare. The third study suggested that dimming forward lighting is effective to reduce glare to oncoming vehicles in lit areas.

Motorway beam

How can motorway beams be achieved?

A motorway forward lighting beam pattern is one that increases light down the roadway in response to high speed conditions. Motorway light can be ideally achieved by adding an additional static beam, increasing the central visual field. It is also possible to simply tilt the conventional high beams by 0.25 to 0.5 degrees up. In the latter case, European beams may be more effective than the US beams. Manufacturers' target of motorway beams is 120-200 m in beam throw distance and 3-5 lx in illuminance. This target was set based on stopping distance.

Can motorway beams improve visibility and satisfaction of drivers?
To consider this question, at least three studies conducted thorough illuminance calculations and field studies. The results consistently showed positive responses in terms of visibility and satisfaction.

Adverse weather beam
How can an adverse weather beam improve visibility and traffic safety?
To increase forward visibility in perturbed atmospheres, some studies recommend using a headlamp system with a narrow beam distribution and a larger displacement from the driver's line of sight. It is believed that wide, short-throw luminous intensity distributions may provide a better solution for wet roadways. Results of a recent LRC study, which established a model to predict forward visibility under adverse weather conditions, support those recommendations. The model suggests that increasing the intensity of light, narrowing the beam width, and increasing displacement of the light source from the line of sight could increase forward visibility. However, it is still unknown how wide or short the headlamp beam distribution should be. Since little evidence was shown, field studies need to be conducted to verify the validity of these ideas.

Unfortunately, reports on these studies do not generally supply enough information, such as light levels, specific beam distributions, and experimental procedures. Additionally, the majority of these studies did not use common performance metrics that have been proven to be related to traffic safety. These factors make it difficult to reproduce the studies (and thus, the results), generalize the findings to other conditions, and ultimately determine the effectiveness of AFS. The overall conclusion of this review is that further research is needed to determine useful metrics for evaluating and comparing AFS systems.

Regardless of the limitations mentioned, all current research on AFS was reviewed and summarized to better understand the current status of AFS. The next section will review those relevant articles and discuss future potential studies.

5.3 Literature review and analysis
This section contains an analysis of relevant AFS literature. The analysis is organized into seven different sections: four sections are dedicated to beam types (bending beam, town beam, motorway beam, and adverse weather beam), the fifth section covers regulations, the sixth section covers technology, and the last section discuss further fundamental studies. Each section begins with a brief introduction describing the major characteristics of the beam function and summarizing the main points of the section. This is followed by a table summarizing the methodologies used in the literature review of that particular section and a discussion of the main findings. At the end of the section is a list of the relevant documents pertaining to the findings and a list of any supplemental information sources.

5.3.1 Overall benefits and acceptance of AFS
This literature survey found that most AFS functions including bending beam, town beam, and motorway beam may increase drivers' visibility and reduce glare to oncoming vehicles in specific traffic scenarios. Results of a field study using 53 subjects suggested that town beam, bending beam, and motorway beam were all highly rated by subjects in terms of driver satisfaction and feelings of safety, and the motorway beam obtained the highest score among the

AFS functions (Hamm, 2003). However, it has not been shown whether those AFS functions can improve traffic safety, as defined by correlations with reduced crash rates.

5.3.2 Bending beam

A bending beam system is vehicle forward lighting with an automatic directional control that turns light into road bends in order to direct the available light where it is needed. The bending beam is intended to improve safety, comfort, and convenience for the driver by increasing forward visibility. For standard (non-bending) headlamps, it becomes more difficult to illuminate forward road surfaces as the curve radius decreases. Accident data collected by the Federal Highway Administration (FHWA) indicate that crash rate increases disproportionately as curve radius decreases. Von Hoffmann (2001) and Schwab (2003) analyzed the FHWA accident data and found that radii of less than 100 m are associated with the highest crash rates. Von Hoffmann (2001) further compared crash rates for equivalent curve radii for daytime and nighttime (Figure 5.1). While the trends were similar, the number of nighttime crashes appears to be larger for curve radii less than 350 m. This implies that appropriate automobile forward lighting, i.e., bending beam, may reduce accidents on curves with relatively small radii, although other causal factors, such as higher proportion of drunken and sleepy drivers at night, might also increase the accident number.

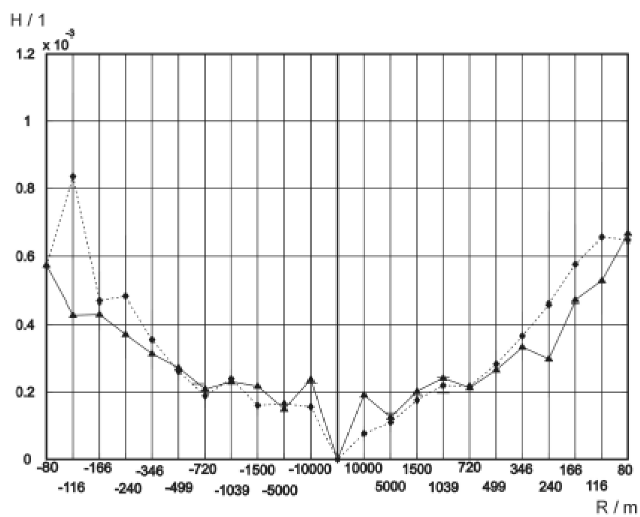


Figure 5.1. Accidents in curves occurring in Washington state, 1993 to 1996.
According to HSIS Database (after Von Hoffmann, 2001). Solid circles represent nighttime accidents on unlit roads. Solid triangles represent daytime accidents.

Before discussing human factors research on bending beam, this review takes note that currently many technical variations of the bending beam exist. There is a static bending system and at least three forms of a dynamic bending system: (1) *one-lamp swivel* (ά and 0°: one lamp swivels by ά degrees); (2) *two-lamp symmetric swivel* (ά and ά: both lamps swivel by ά degrees); and (3) *two-lamp asymmetric swivel* (ά and ά /2: one lamp swivels by ά degrees and the other lamp swivels by ά/2 or $\acute{\alpha}_1 < \acute{\alpha}_2$ degrees). These variations are depicted in Figure 5.2 below.

The variety of bending systems alone presents a host of questions. While ultimately the cost/benefit ratio will likely determine which bending system is adopted by the automobile industry, manufacturers are presently in the early stages of determining the advantages/disadvantages associated with each system.

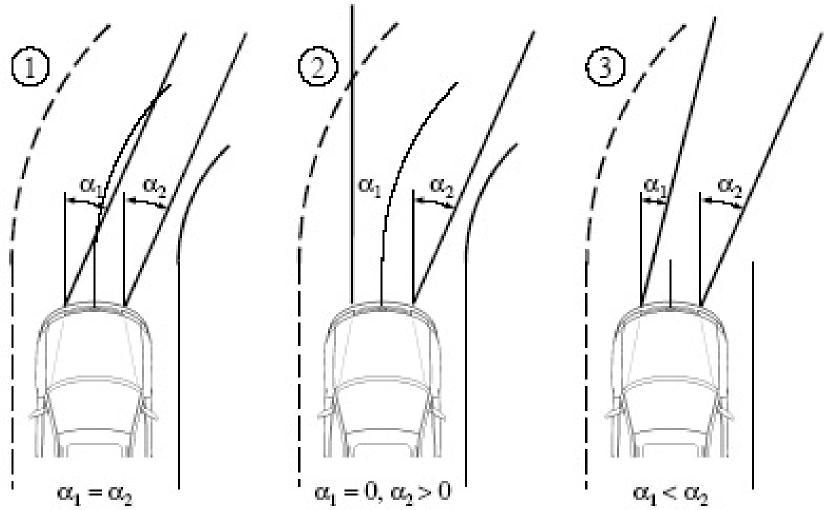


Figure 5.2. Three forms of dynamic bending beam systems. (1) Two-lamp symmetric swivel (2) one-lamp swivel (3) two-lamp asymmetric swivel (after Schwab, 2003).

Bending beam methodology

To aid the review process, it was decided to look at what studies have been conducted in terms of visibility (forward and peripheral), eye fixation point, and glare. Within this context, the terminology "standard system" refers to non-AFS headlamp systems. Table 5.1 summarizes the reviewed studies and their methodologies.

Table 5.1. Bending beam methodology summary.
Beam type: E = Europe; J = Japan; NA = North America.

Beam	Study	Dependent Variables	Methodology	Scenario	Subjects
E	Diem, 1999	eye tracking	3 system comparisons: static halogen, bending halogen, bending HID	test track, straight and 110m radius curve	10
E	Diem et al., 2003	subjective brightness ratings, acceptance evaluations, eye tracking	4 system comparisons: one-sided swivel, parallel symmetric swivel, assymetric swivel, standard static	field test, 43m and 293m radius curves	?
E	Grimm, 2001	small target detection	dynamic bending beam compared with static beam	moving targets for stationary drivers; 200m and 400m radius curves	11
E	Hamm and Rosenhahn, 2001	small target detection, subjective evaluation of comfort	comparison of standard halogen, standard HID, and AFS HID prototype	250m radius curve, and a straight	11
E	Hamm, 2002	subjective evaluation of visibility	3 system comparisons: one-sided swivel, parallel symmetric swivel, assymetric swivel	field test in town, motorway, and curves	43
J	Hara et al., 2001	eye fixation	comparison of 2 halogen systems: static and AFS	lefthand field test, 40m radius curve	3 males

Table 5.1. (cont.) Bending beam methodology summary.

Beam	Study	Dependent Variables	Methodology	Scenario	Subjects
E	Hogrefe, 2000	in-house subjective evaluation of visibility	comparison of 2 static and one bending+static system	curves of different radii	none
J	Ikegaya and Ohkawa, 2003	computer simulation illuminance calculation, small target detection	4 system comparisons: one-sided swivel, parallel symmetric swivel, assymetric swivel, standard static	50m radius S-curve: illuminance calculated using computer simulation, small target detection measured in a field test	?
J	Ishiguro and Yamada, 2004	eye fixation	dynamic bending headlamp system evaluation	test track: 20-250m radius curves, 30,45, & 60 km/h speeds	10 daytime, 3 nighttime
J	Kobayashi and Hayakawa, 1991	prototype evaluation	low beam photometric (illuminance) data analysis	low and high speed driving on straights and curves	none
J	Kobayashi et al., 1997	calculated deBoer discomfort glare based on illuminance measurements	comparison of static halogen and static HID low beams	140m radius curve	none
J	Kobayashi et al., 1999	subjective evaluation of visibility	comparison of various static and bending HID and halogen systems	4km test course with bends, slopes, intersections, and straights	8
J	JARI, 2001	eye tracking, illuminance profile calculation	comparison of a standard non-AFS, one-sided bending, and symmetrical two-sided bending system	4 turns: lefthand, righthand, left S-curve, right S-curve	?
NA	McLaughlin et al., 2003	subjective evaluation of discomfort glare	comparison of 2 HID systems: one static and one bending	left and righthand curves, r=80m and 180m	16
E	Neumann, 2003	recognition distance of target letters E,M, and H; braking reaction time for dummy pedestrian)	2 halogen system comparisons: standard and dynamic bending	test track	?
J	Sato et al., 2001	calculated deBoer discomfort glare based on illuminance measurements	low beam photometric (illuminance) data analysis	right and lefthand curves, a straight	none
E	Schwab, 2003	small target detection	5 system comparisons: one-sided swivel, parallel symmetric swivel, assymetric swivel, static HID, and static halogen	moving targets for stationary drivers; various curves ranging from 75m to 300m radius	?
NA	Sivak et al., 2001	illuminance calculations	illuminance calculations using market-weighted US and European non-AFS beam distributions	left and righthand curves, radius=80m and 240m	none

Table 5.1. (cont.) Bending beam methodology summary.

Beam	Study	Dependent Variables	Methodology	Scenario	Subjects
NA	Sivak et al., 2002	calculated deBoer discomfort glare based on illuminance measurements	comparison of standard US and European beam patterns	calculations for left and righthand curves, r=240m	none
NA	Sullivan et al., 2002	subjective evaluation of discomfort glare	comparison of 2 systems: one static and one bending	2 turns, left and right	?
J	Wada et al., 1989	eye fixation, driving "ease"	test track, car equipped with dynamic bending reflector lights and an eye tracker	left and righthand curves	10, aged 20-60
J	Watanabe et al., 2001	subjective evaluation of small target visibility, luminance target contrast calculation	standard halogen, HID, and dynamic system comparisons	16m, 55m, and 80m radius curves	5, aged 20-59
J	Yamamoto, 2004	computer simulation illuminance calculation	evaluation of a swiveling halogen system	turns	none

Bending beam main findings

The research conducted on bending beam functionality is quite extensive; therefore, the results of this research have been divided into three sections: forward visibility, eye fixation, and glare. Due to the lack of published information and conflicts of results, this survey could not clearly identify whether a bending beam improves forward visibility, reduces glare, and increases traffic safety and which of the three typical dynamics—a one-lamp swivel, a two-lamp swivel with the same bending angle, and a two-lamp swivel with different bending angles—performs best. The following summarize the status of bending beam research.

Forward visibility

On forward visibility, this study reviewed Wada et al. (1989); Kobayashi and Hayakawa (1991); Kobayashi et al. (1999); Hogrefe (2000); Hamm and Rosenhahn (2001); Grimm (2001); Japan Automobile Research Institute, Inc. (JARI, 2001); Sato et al. (2001); Watanabe et al. (2001); Hamm (2002); Sivak et al. (2002) Diem (2003); Ikegaya and Ohkawa (2003); Neumann (2003); and Schwab (2003).

A variety of prototype headlamp beams were tested in laboratory and field tests. Therefore, most studies were primarily conducted by manufacturers who have the ability to develop prototype models. Since specifications of AFS products tend to be confidential, it was not possible to collect enough information to objectively analyze experimental design and findings for most references in this literature survey. However, among those listed, the most comprehensive studies on visibility with bending beam were ones conducted by JARI (2002) and Sivak et al. (2001).

Through the survey of the above listed studies on forward visibility, the following findings were identified:

- A static component (variation of the cornering beam) proved to be more effective than a dynamic (movable) component in illuminating curves of small radii and intersections, while a movable component was necessary to illuminate curves of larger radii (specific information of radii not provided).
- With a system using a movable component alone, the larger angular rotation required for curves of small radii resulted in a period of time when illumination, in the forward direction, was unsatisfactory.
- Within an S-curve, the crossover point—the turning point from a left-hand curve to a right-hand curve or vice versa—was most effectively illuminated by a standard headlamp system vs. all varieties of a bending beam system tested.
- The data are inconsistent on which type of bending system is better. However, with certain types of bending beams under certain conditions (vs. a standard system), an increase in visibility was demonstrated.

The concern in this section is primarily which type of bending beam systems provides the best forward visibility among four bending beam options: (1) static bending beam; (2) one-lamp swivel (ά and 0°); (3) two-lamp symmetric swivel (ά and ά); and (4) two-lamp asymmetric swivel (ά and ά/2).

JARI (2002) investigated illuminance distribution under three different types of beams: a standard (non-AFS) beam, a one-lamp swivel, and a two-lamp symmetric swivel (HID lamps) for several computer-generated scenarios. The illuminance calculations were conducted for the road edge, middle of driving lane, and center line. This study used four curve scenarios: right- and left-hand curves and two S-curves (left-hand curve turning into right-hand curve, and right-hand curve turning into left-hand curve). Figure 5.3 shows an example of the illuminance profile calculations comparing three headlamp types.

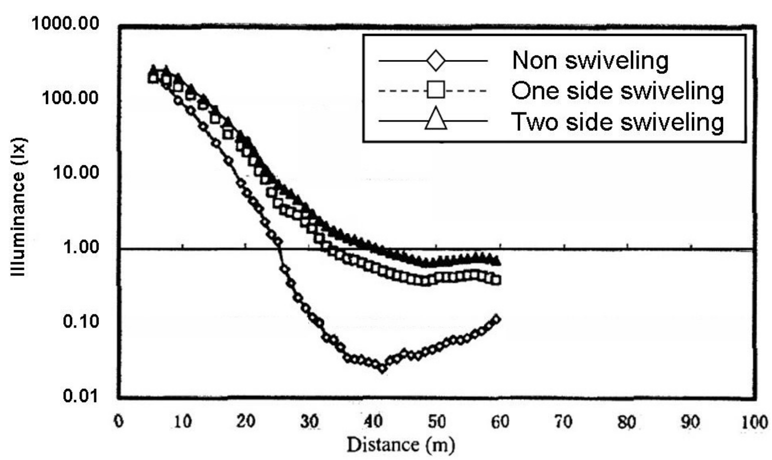


Figure 5.3. Illuminance of middle of driving lane at entry point of S-curve.
Left-hand curve turning into right-hand curve, R=30 m, swivel angle=13 degrees (after JARI, 2002).

One of the findings of the calculation was that the two-lamp symmetric swivel system generally provided up to three times more light than the standard system. However, there are some exceptions listed below (note that Japan uses a left-hand traffic system):

- Left-hand curve turning into right-hand curve: As the simulation vehicle enters the point of crossover within the S-curve, the three areas, road edge, middle of driving lane, and center line, some distance ahead of the vehicle receive less light with the AFS systems than with the standard system.
- Right-hand curve turning into left-hand curve: the 30 m radius curve simulation indicated a decrease in illuminance for the AFS systems, although all other radii showed an increase in illuminance with AFS. Throughout the curve, the two-lamp swivel system provided the least amount of light at all distances compared to the one-lamp swivel and the standard non-AFS system. Likewise, the one-lamp swivel system provided less light than the standard system at all distances ahead of the vehicle. Despite the decreases in illuminance, the light levels were still adequate for visibility.

Ikegaya and Ohkawa (2003) also calculated illuminance distributions on the roadway surfaces for four different beam types: a standard system, a one-lamp swivel system (ά and 0°), a two-lamp symmetric swivel system (ά and ά), and a two-lamp asymmetric swivel system (ά and ά /2). A scenario, an S-curve beginning with a right curve followed by a left curve with a radius of 50 m and a turning acceleration of 0.4 G, was used in this calculation study. Figure 5.3 shows an example of the calculation results. The results suggest that illuminance is highest with the two-lamp (symmetric and asymmetric) swivel systems. In the first right curve portion of the S-curve, the standard system provides the lowest illumination for approximately the first four-fifths of the curve; however, just before the crossover point, the standard system provides the highest illumination. Both two-lamp swivel systems provide the least amount of illumination at a moment just before the crossover point. The one-lamp swivel system also decreased in illumination at the crossover point, though not as much as with the two-lamp systems. In the beginning of the left curve, the standard system gave the least illumination, followed by the one-lamp system, and then the two-lamp systems. Both two-lamp systems provided comparable illumination.

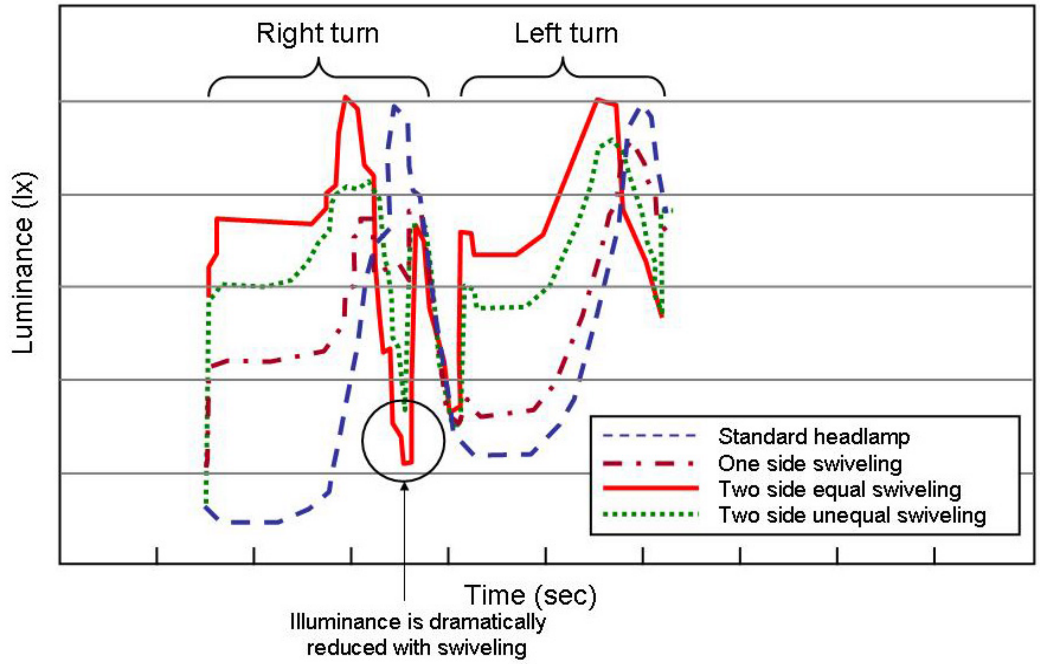


Figure 5.4. Example of illuminance calculation at a point (after Ikegaya and Ohkawa, 2003).

Unfortunately, since this study used a headlamp beam distribution that meets Japanese regulatory standards, the results could not be directly adopted to headlamps in the United States. Similar studies using illuminance calculation need to be conducted for US headlamp beam distributions.

Another method to compare the performance of bending beams is subjective evaluations. Many studies used this method in the field. Unfortunately, because detailed information on luminous intensity distributions of headlamps tested by those studies is unavailable, it is impossible to identify physical requirements for bending beams. For instance, Hogrefe (2000) used subjective evaluation to evaluate three types of bending beam systems—two static beams, and a combination of static and dynamic beams. The systems consisting of static beams alone performed worse, in terms of forward visibility, than the system utilizing the combination movable and static beams. However, the author concluded that the static component was still beneficial to AFS.

Additionally, there are two recent studies comparing bending beam systems using subjective evaluation. Hamm (2002) conducted a field test to evaluate visibility with three bending beam types: one-lamp swivel (ά and 0°), two-lamp symmetric swivel (ά and ά), and two-lamp asymmetric swivel (ά and ά /2). The results suggested that the asymmetric swivel system was rated as most satisfactory in terms of visibility, followed by the symmetric swivel. The one-lamp swivel, though rated as the least satisfactory, was still considered to provide adequate illumination. Although this study used 43 subjects, detailed data with statistics were not included in this paper. Diem (2003) also conducted a field test comparing three variations of a bending beam system by using subjective brightness and overall acceptance evaluations and eye movement analysis. The authors compared a one-lamp swivel, a two-lamp symmetric swivel, a two-lamp asymmetric swivel, and a standard system. The results of the subjective brightness evaluations indicated that the two-lamp systems performed better than the standard and one-lamp systems. The results also indicated that the one-lamp swivel system was no better in overall performance (considering both left- and right-hand curves) than the standard system, while the symmetric system was rated highest overall. Although there was a slight conflict between the two studies, both studies suggested two-lamp swivel systems were better than the one-lamp swivel or standard headlamp systems in terms of subjective evaluation.

To more objectively compare the potential bending beam systems, other studies attempted to use target detection. For instance, Grimm (2001) tested target (40 cm x 40 cm, reflectance = 0.08) visibility as a function of curve radius using a prototype dynamic bending beam. For a right-hand curve, the dynamic bending beam increased target visibility, implying that drivers can have longer detection distances along small-radius curves with a dynamic bending beam than a standard headlamp system. Ikegaya and Ohkawa (2003) conducted a similar field study evaluating if illuminance at the crossover point within an S-curve was adequate to allow for a sufficient stopping (braking) distance. The authors indicated that illumination was adequate in order for the driver to avoid an obstacle and stop at a safe distance. Among standard, one-lamp swivel, and two-lamp swivel systems, this study did not find any significant differences in detection distance.

A similar study was conducted with left- and right-hand curves with radii ranging from 100 m to 500 m (Schwab, 2003). The results suggested that all three variations of the swivel system performed comparably, and for a left-hand curve with r=100 m, target detection increased over the standard HID system by approximately 10 m. Target detection for curves with r =200 m and r=300 m did not demonstrate improvement over the standard HID system. However, for curves with r=500 m, target detection using the AFS system increased 15-25 m over the standard HID system. For the right-hand curve scenario, the AFS system demonstrated improvement in target detection only for those curves with r=100 m (AFS increased detection distance by approximately 10 m). The author also states that for sharp curves of small radii, the use of an additional static component (e.g., a cornering light) are recommended. From these results, it can be concluded that, in general, two-lamp swivel systems (regardless of symmetry) are just as good or better than standard (non-AFS) or one-lamp bending beams, although in some instances the difference in detection distance was small.

The above described studies used European and Japanese headlamp patterns. It is still questionable if those results can be applied to US headlamp beams. To compare US headlamp beams with European beams, a recent study used calculations to compare beam types (Sivak et al., 2001). The authors used standard (non-AFS) headlamps from the US and European market-weighted models (year 2000). To simulate bending beams, the authors rotated the beam patterns at certain angles and calculated illuminance distributions for different scenarios including left-hand and right-hand curves (radius = 80 m and 240 m). This study simulated bending beams for a curve with r=240 m (high speed scenario) and r=80 m (low speed scenario) by shifting the beam pattern horizontally by 10 degrees and 15 degrees, respectively. Illuminances were calculated along the right edge line of the lane of travel. It was found that the illuminances were similar for both radii. The illuminance calculation concluded that visibility in a curve would be increased with a beam pattern shifted horizontally in the direction of the curve. The horizontal shift resulted in approximately one-half to a full log unit more light than the standard headlamps. This study found similar tendencies for the US and European standard beams. This implies that bending beam can provide higher visibility of targets on the pavement and that the European data on bending beam functionality can be applicable to US headlamps for visibility.

In Europe, many studies evaluated bending beams, suggesting that the bending beam is better than standard headlamps. However, the manufacturers that conducted these studies most often did not publish detailed information. It is impossible then to repeat the experiment or check the reliability of the data. Sivak et al. (2001) started bridging the gap between the United States and Europe regarding bending beam studies with computer simulations. Since the cutoff angle of US standard headlamps is less strict than for European headlamps, more visibility improvements through bending beams can be expected. Further evaluation of the effects of bending beams using US headlamp beam distributions is necessary.

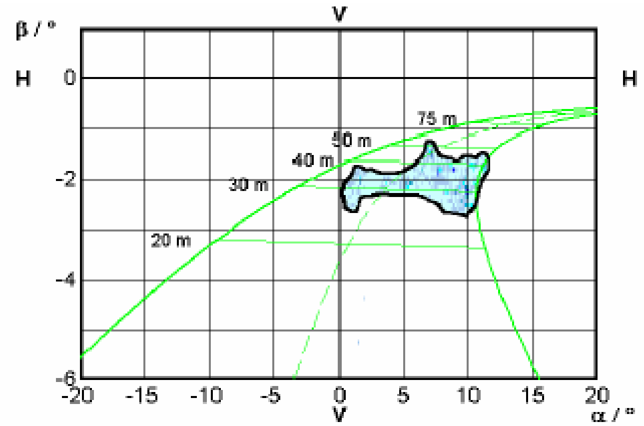
Eye fixation

The LRC reviewed six studies that analyzed eye movement behavior as a tool to evaluate the effects of bending beam on drivers' performance. These studies were Wada et al. (1989); Diem et al. (1999); Hara et al. (2001); JARI (2001); Diem (2003); Ishiguro and Yamada (2004).

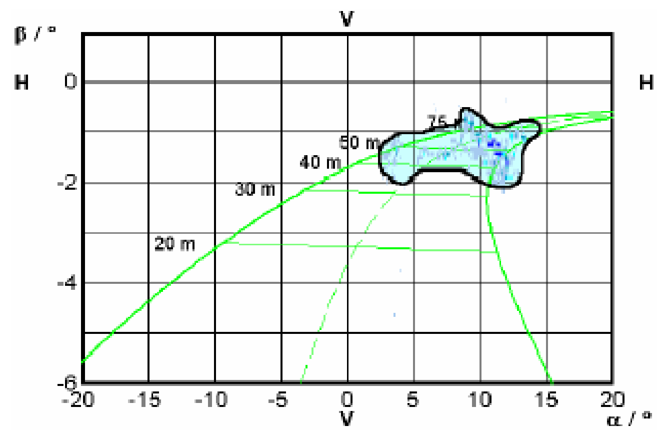
These studies used different methods to interpret eye fixation data. One method considered that, since eye fixation is a function of light distribution, a better light distribution may more appropriately induce eye movement (e.g., Diem et al., 1999; Diem, 2003). The other methods assumed that, since a driver's anticipation of a given curve has a dominant influence on eye fixation point, the headlamps' light distribution might not affect eye movement (e.g., Hara et al., 2000; JARI, 2002). The interpretation of eye fixation data is inconsistent among studies, and therefore the methodology using eye movements for evaluating headlamps is questionable. While some studies suggested that the AFS bending beams generally allow drivers to see longer distances than a conventional fixed headlamp system (e.g., Diem, 2003), other studies concluded that the results could not prove that AFS bending beams induce eye movements (e.g., JARI, 2001).

Recently, Diem (2003) repeated an eye tracking study to confirm his previous findings (Diem et al., 1999). The author evaluated eye fixation under the illumination of a standard headlamp system, a one-lamp swivel system, and a two-lamp symmetric swivel system. Those three variations used the same headlamp beam pattern but different moving capabilities. Figure 5.5 shows the results of the eye fixation evaluation. The author succeeded in finding a tendency similar to his older study (Diem et al., 1999). Again, the eye fixation points appear to be a function of illuminance distribution. For the right-hand curve, under illumination from the standard headlamp system, mean fixation distance was 32 m in front of the vehicle; for the one-lamp swivel system, mean fixation distance was 40 m; for the two-lamp symmetric swivel system, mean fixation distance was 60 m. This implies that bending beam induces further eye fixation points along curves than standard headlamps.

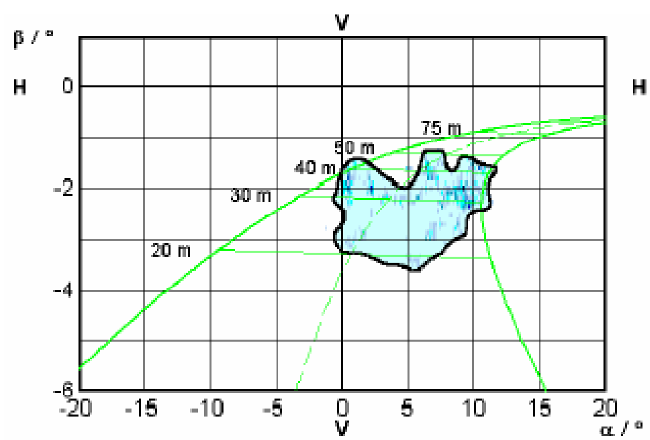
Since results in such studies may be influenced by instructions in experiments and novelty of systems, this information should be mentioned in reports. However, none of the studies reviewed provided such information.



(a) Mean fixation area while driving through a right-hand curve (radius=294 m) with standard headlamps. The mean fixation distance is 32 m in front of the car.



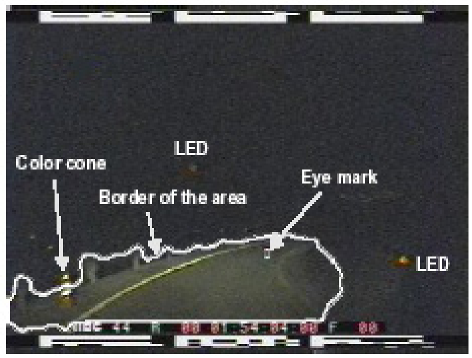
(b) Mean fixation area while driving through a right-hand curve (radius=294 m) with two-lamp symmetric swivel system. The mean fixation distance is 60 m in front of the car.



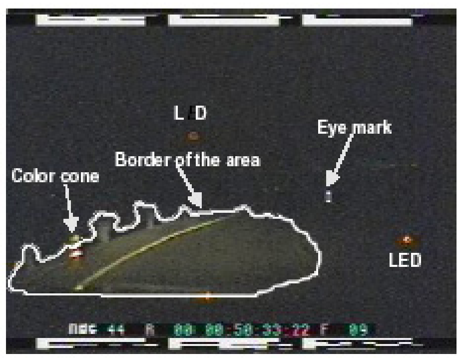
(c) Mean fixation area while driving through a right-hand curve (radius=294 m) with one-lamp swivel system. The mean fixation distance is only 40 m in front of the car.

Figure 5.5. Comparison of eye fixation points (after Diem, 2003).

On the other hand, Hara et al. (2001) found that eye fixation was not always dictated by light distribution. The authors evaluated a standard headlamp system and an AFS headlamp system (no further details provided). Eye fixations with the AFS system appeared to follow the bending beam and maintained position within the area illuminated. Eye fixations under the standard system were not limited to the area illuminated and extended beyond the illuminated area further into the curve. For a right curve, the average point of fixation with the AFS system was mostly on the inside of the right-hand curve (Figure 5.6). Under the standard system, the average point of fixation was on the outside of the curve.



(a) AFS-ON on a right curve.



(b) AFS-OFF on a right curve.

Figure 5.6. Eye fixation points and bending beam function (after Hara et al., 2001).

JARI (2001) conducted a similar but larger scaled study using eye movements as an objective index of headlamp performance. This study tested a one-lamp swivel system and a two-lamp asymmetric swivel system on a test track (driver on left-side lane). The principle conclusion was that swiveling headlamps did not affect the line of vision. When entering a curve, the authors noted that the driver's gaze followed the curve quicker than the swivel system could operate. For right- and left-hand curves, the frequency of driver gaze at the center line was equivalent to the frequency in the daytime. The frequency of gazing at the center line was increased as the radius of a curve increases. At nighttime, road-edge detection became more of an area of focus; at nighttime 80-90% of fixations were directed toward the road-edge while during daytime, the frequency of fixation on the road edge was only 60-70%. Upon entering a curve, eye fixation occurred at a point just before curve entrance and moved toward the end of the curve. For right-hand curves, drivers extended their gaze to see as much of the center line as possible. For left-hand curves, drivers extended their gaze to road surface edge/shoulder. After entry, as well as throughout the curve, the behavior described above persisted. The authors noted that although the drivers gazed at the illuminated area when AFS was operating, similar tendencies of fixation were seen during the daytime. When exiting a curve onto a straightaway, the driver's fixation point moved from the exit point of the curve toward the distance.

A recent study (Ishiguro and Yamada, 2004) compared eye fixation points between daytime and nighttime. The test course consisted of curves with radii ranging from 20-250 m. The results suggested that for the right-hand curve at night, the frequency of eye fixation toward the center line increases compared to daytime behavior. For the left-hand curve, the frequency of eye fixation toward the left-road shoulder increases compared to daytime behavior. This suggests that eye fixation points at night move more than daytime eye fixation points. However, this tendency conflicts with that of Diem et al.'s study (1999).

Through this literature survey of eye fixation, conflicting data make it apparent that the fundamental mechanisms of eye movements are not completely understood. It is still unclear whether traffic safety is increased as drivers' fixation points move further away from the drivers or even where drivers should be looking to improve traffic safety. These fundamental issues need to be addressed if the methodology of eye movement analysis is to be applied in assessments of the bending beam.

Glare

While many studies addressed discomfort glare in bending beam evaluations, few studies dealt with disability glare. This is probably because the influences of headlamps on disability glare are constant whether headlamps are swiveled or not (JARI, 2002). The LRC reviewed the following eight studies discussing discomfort glare: Kobayashi et al. (1997); Grimm (2001); Hamm and Rosenhahn (2001); JARI (2001); Sato et al. (2001); Sullivan et al. (2002); Sivak et al. (2002); and McLaughlin et al. (2003).

A common metric used for discomfort glare is the de Boer scale (1=unbearable, 2, 3=disturbing, 4, 5=just acceptable, 6, 7=satisfactory, 8, 9=just noticeable). Some studies used the de Boer scale to subjectively evaluate discomfort glare. Other studies relied on computer simulations rather than subjective evaluations. Another group of studies measured illuminance at the driver's eye, or glare illuminance. Although no studies clearly stated that glare illuminance is proportional to the perceived degree of glare, most studies seemed to assume good correlation between glare illuminance and glare perception. Although there is agreement on the calculation of disability glare by veiling luminance at the driver's eye position[2], few studies used this metric.

The main concern is whether the bending beam causes more glare than a standard headlamp. A variety of prototype beams (or combinations of beams) have been tested. Two studies, in which the statistical analyses are well-documented, demonstrated conflicting results. Sullivan et al. (2002) found a bending beam system to be significantly glarier than a standard system, while McLaughlin et al. (2003), with the exception of an 80 m radius left curve, found a bending beam system to be significantly less glary than a standard system. What caused such differences between the two experiments? The answer to that question may depend on the scenarios and

[2] Vos, J.J. 1962. *On mechanisms of glare, Institute for perception*, RVO-TNO Publication, Soesterberg, The Netherlands.

types of bending beams used. Bending beam-equipped headlamps following the US SAE standards might cause more glare than European or Japanese standard conforming bending beams because the US cutoff angle is less strict than the others. Whether the headlamp is a projector type or a reflector type may be another factor influencing glare.

Sullivan et al. (2002) conducted a field study on discomfort glare comparing a bending beam and a non-bending beam. The bending beam was a prototype that did not follow either the SAE or ECE standard (one of the co-authors, Michael Flannagan, provided this information). The oncoming driver vehicle was stationary, while the test vehicle equipped with the bending beam was moving. The bending beam was a prototype swivel headlamp with a horizontal swivel range of 17 degrees. The speed of the bending beam vehicle was approximately 24 km/h, and it made both left and right turns 33.6 m in front of the stationary vehicle. Subjects were asked to assign glare ratings (de Boer scale) after experiencing the AFS vehicle turn in front of them. The results from 17 subjects suggested that the effect of the bending beam on discomfort glare was significant. Averaged de Boer ratings were as follows: for bending beam, 5.07; for non-bending beam, 6.45. The bending beam caused more glare than the non-bending beam. No main effect of turn direction was demonstrated. However, there was a significant interaction between the bending beam and turn direction. Left turns illuminated by the bending beam were rated as more glaring than right turns illuminated with the bending beam (de Boer rating of 4.82 for left turn; 5.33 for right turn). Glare associated with the non-bending headlamp demonstrated opposite results (de Boer rating of 6.65 for left turn; 6.26 for right turn).

McLaughlin et al. (2003) conducted a field study in a paved parking lot. The study evaluated discomfort glare caused by dynamic high intensity discharge (HID) headlamps (bending beam) compared to fixed HID headlamps (non-bending beam). Both bending and non-bending beams were projector-type headlamps of a 2000 Cadillac Seville. This paper did not state whether the tested headlamp beams conformed to the SAE standard. Subjects, ranging from 57 to 65 years in age, rated discomfort glare of the two types of headlamps by using the de Boer scale in eight different driving approach scenarios: (1) making a large right turn (radius r=180m); (2) making a large left turn (r=180m); (3) making a smaller right turn (r=80m); (4) making a smaller left turn (r=80m); (5) turning left beside a participant vehicle at an intersection; (6) turning left in front of a participant vehicle; (7) turning right beside a participant vehicle; and (8) driving on a straight lane. Figure 5.7 shows the results of the glare evaluations. The results suggested that swiveling headlamps provided equivalent or reduced discomfort glare in most scenarios except scenario (8), driving on a straight lane. It was also found that HID headlamps regardless of the headlamp type (swiveling or non-swiveling) were acceptable, larger than 5 on the de Boer scale, in a wide range of approach scenarios. Most other studies using European standard headlamps provided similar results to McLaughlin et al.'s study.

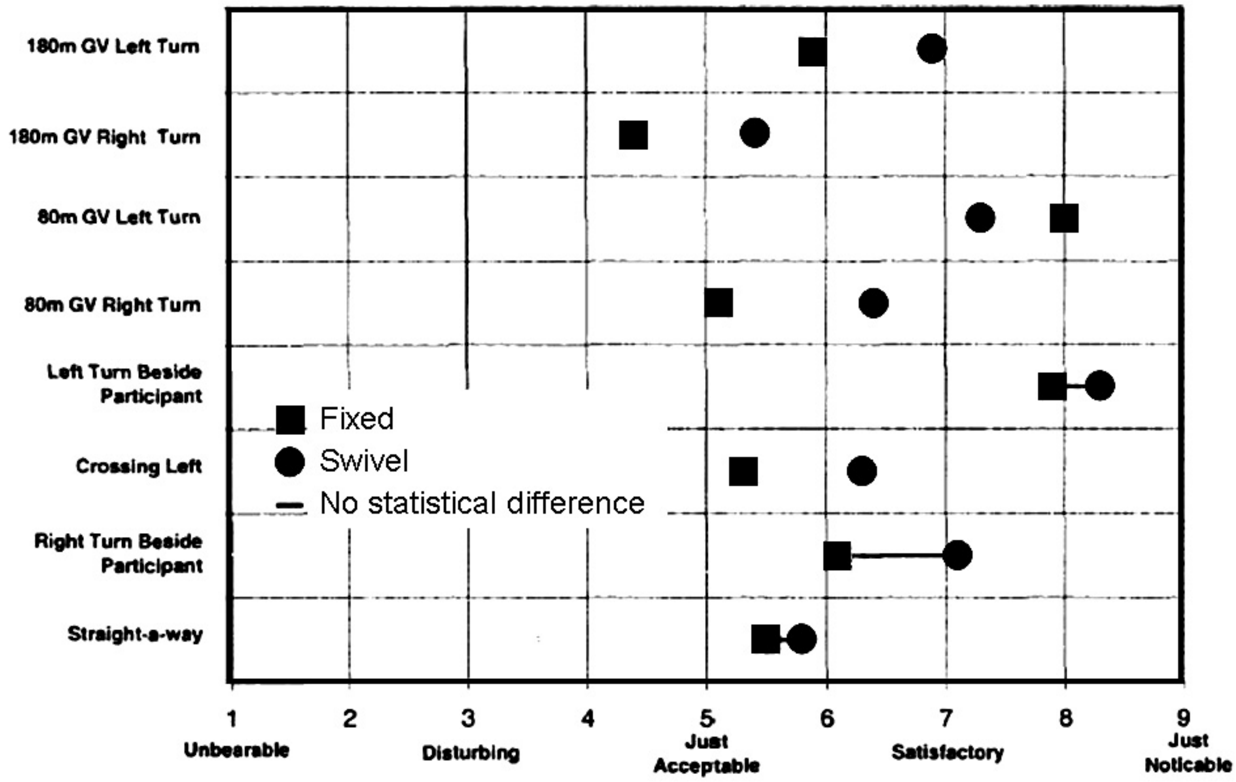


Figure 5.7. Glare evaluations using the de Boer rating (after McLaughlin et al., 2003).

The results of the McLaughlin et al. study conflict with those of the study from Sullivan et al. (2002). The cause of this conflict can probably be attributed to differences in headlamp beam patterns used in the two studies. Additionally, Sullivan et al. might have used reflector-type headlamps while McLaughlin et al. used projector-type headlamps.

On the effects of difference between the SAE and ECE standards on glare, a simulation study compared US headlamps with European headlamps. Sivak et al. (2001) used the US and European headlamp beam patterns found in earlier UMTRI studies and modified them to simulate the bending beam. The modification entailed shifting the headlamp horizontally. This study calculated, for left- and right-hand curves with r=240 m, illuminance at 1.11 m above the ground at distances from the headlamps between 50-175 m. Figure 5.8 shows the results. Both US and European headlamp beam patterns show similar trends in illuminance at the eye, with the US beam consistently producing more illuminance at the eye than the European beam, and the horizontally shifted US beam consistently producing more illuminance at the eye than the non-shifted beam.

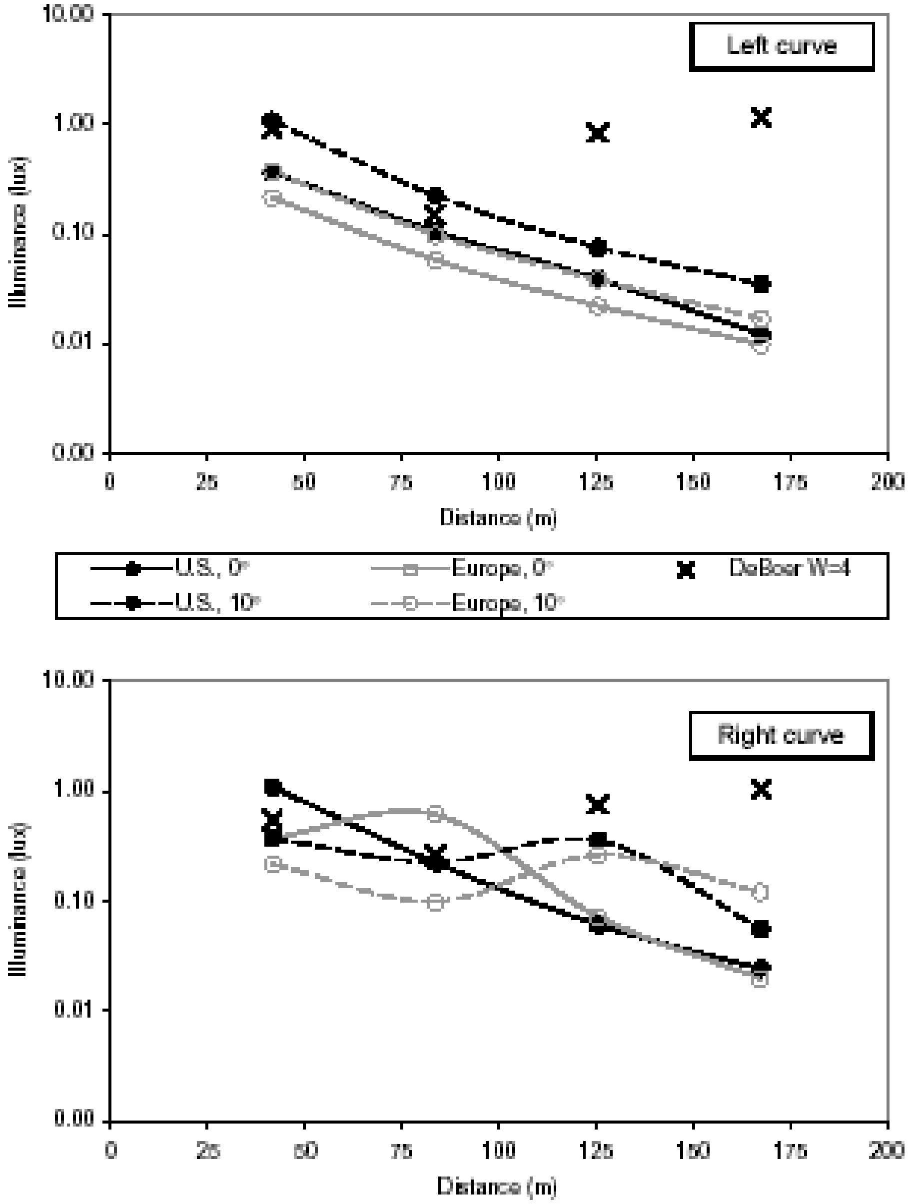


Figure 5.8. Glare illuminances (after Sivak et al., 2001).
Glare illuminance reaching the eyes of an oncoming driver on curves with a radius of 240 m from US and European low beams, with nominal aim and a 10 degree beam shift into the curve (also included are illuminances needed for a de Boer discomfort glare rating of 4—threshold of glare tolerance).

A Japanese study (JARI, 2002) may also bridge the gap between the US and Europe studies, since the glare cutoff angle of Japanese headlamp standards is stricter than that of the US standard but looser than that of the ECE standard.

JARI (2002) conducted a field study and a computer simulation with regard to glare. (Note that vehicles operate on the left side in Japan.) This study used a unique method to evaluate glare from a bending beam. The field study used a passenger car equipped with five CCD cameras covering a 100° wide and 15° high visual field. The five cameras videotaped oncoming vehicles while the car was driven 435 miles along public roads. The study analyzed the oncoming drivers' eye level positions under various geometrical conditions such as left- and right-hand curves and S-curves. From images videotaped by five CCD cameras, JARI analyzed whether oncoming drivers' eye levels were above or below the cutoff line of the headlamp beam distribution of conventional non-swiveling and swiveling headlamps. The eye levels of the oncoming drivers were determined at a distance of 50 m in front of the test vehicle. The assumption behind the criterion was that, if an oncoming driver's eye level was below the headlamp cutoff line, the headlamps caused discomfort glare to the oncoming driver. The results of the analysis on left-hand curves indicated that approximately 30% of the oncoming drivers' eye levels were below the cutoff lines for non-swiveling headlamps compared to less than 15% for swiveling headlamps. In other words, swiveling headlamps produced glare to oncoming drivers in fewer cases than conventional non-swiveling headlamps. For right-hand curves, there were no eye levels recorded that fell below the beam cutoff line for any beam configuration. Therefore, neither swiveling nor non-swiveling headlamps could have imparted glare to oncoming vehicles in this case.

The computer simulation study calculated vertical illuminances at drivers' eye positions and veiling luminances on drivers' central visual fields under various roadway geometry conditions for three headlamp types—conventional non-swiveling, one-lamp swiveling, and two-lamp swiveling headlamps. The calculation was done with a high beam (the term "passing beam" was used) headlamp distribution pattern. On left-hand curves, the peak eye illuminances with one-lamp and two-lamp swiveling headlamps were lower than that with non-swiveling headlamps. Additionally, the peak eye illuminances with two-lamp swiveling headlamps occurred at further distances from the oncoming drivers, and therefore in earlier stages than conventional non-swiveling headlamps. On right-hand curves, there were no differences in eye illuminance among the three headlamp types. For S-curves, eye illuminances for swiveling headlamps were lower than non-swiveling headlamps. However, the peak veiling luminances for swiveling headlamps were higher than those for non-swiveling headlamps along S-curves formed of left-hand curves turning into right-hand curves. This simulation study also found that two-lamp swiveling system imparts more glare to oncoming drivers when the vehicle is waiting to turn right.

In most scenarios evaluated by JARI (2002) using Japanese headlamps, the bending beam caused less glare than the non-bending beam. The answer to the question of whether bending beams cause more glare than non-bending beams may depend on the scenarios and types of headlamps used. It is necessary to more comprehensively analyze the effect of headlamp types on glare ratings by using various types of headlamps, by comparing the US, European, and Japanese headlamps, and by comparing projector and reflector headlamps. To do this, it is first important to establish criteria in terms of forward visibility and glare. Also important to address are when headlamps should start swiveling before reaching a curve and how fast headlamp orientations should complete their shift. Few studies explored these issues.

Since other studies did not provide detailed data, they are not discussed here. However, summaries with underlined results of glare evaluation for those studies are listed below.

Bending Beam Key References

Summaries of the reviewed studies are listed below in alphabetical order, organized by topic: forward visibility, eye fixation, and glare. Short descriptions of methodology, bending beam types, and scenarios are also listed.

Forward visibility

JARI (2001) calculated illuminance profiles for three bending systems (standard non-AFS, one-lamp bending, symmetrical two-lamp bending) on 4 curve scenarios (righthand, lefthand, and left and right S-curves). Calculations were conducted for the road edge, driving land center, and center line, and were computer generated. Parallel swivel system provided up to ½ log unit more light than standard.

- Methodology: computer-generated illuminance calculation
- Subjects: none
- Types: a standard non-AFS, one-lamp bending, and symmetrical two-lamp bending
- Scenarios: righthand curve, lefthand curve, and left and right S-curves

Sivak et al. (2001) conducted a calculation to compare US and European beams. Market-weighted non-AFS beam patterns were used for calculations to simulate bending beams for curves of different radii.

- Methodology: illuminance calculations
- Subjects: none
- Types: market-weighted US and European non-AFS beam distributions
- Scenarios: left and righthand curves, r=80m and 240m

Eye fixation

Diem et al. (1999) investigated eye movement of drivers with bending beams and standard headlamps. The data showed that the standard HID system resulted in 30.9m and 38.5m for left and right-hand curves respectively, whereas the AFS HID system resulted in 35.8m and 43.5m left and right-hand curves respectively.

- Methodology: Eye-Tracking System
- Subjects: 10
- Types: a standard halogen, a halogen AFS, an HID AFS
- Scenarios: test track (straight away and 110 m radius curve), no other cars

JARI (2001) conducted a field study to evaluate the performance of bending beam by using eye movements. The principle conclusion set forth by the authors is that swiveling of the headlamps does not result in an induced line of vision. The authors also note that when entering a curve the driver's gaze followed the curve quicker than the swivel system could operate. Methodology: Eye movement by using an eye mark recorder (EMR-8)

- Subjects: 4 males, ages 20-30
- Scenario: a test course including various curves of small radii (r=11-13m) and larger radii up to 120m

Glare

JARI (2001) evaluated glare through computer simulations, as well as a field test, which determined oncoming drivers' eye position. (See the above text for more details)

- Methodology: computer simulations (eye illuminance, veiling luminance), a comparison between cutoff angle and drivers' eye positions.
- Types: standard (non-AFS), one-lamp swivel, and symmetrical two-lamp swivel beams (HID lamps).
- Scenarios: Right- and left-hand curves and S-curves (left hand curve turning into right hand curve, and right hand curve turning into left hand curve).

McLaughlin et al. (2003) investigated the discomfort glare imparted to oncoming drivers by comparing a standard HID headlamp system with a swivel HID headlamp system. The authors performed statistical analysis. (See the text for more details.)

- Methodology: subjective evaluation using de Boer rating
- Subjects: 16
- Type: a standard HID headlamp system with a swivel HID headlamp system
- Scenario: Left- and right-hand curves (r=80 m and 180 m)

Sivak et al. (2002) calculated glare illuminance for curves with r=240 m, comparing US and European headlamp beam patterns for standard headlamps. (See the above text for more details)
- Methodology: calculation of de Boer rating.
- Types: US beam and European beam.
- Scenarios: left- and right-hand curves with r=240 m.

Sullivan et al. (2002) conducted a field study. This study actually performed statistical analyses. The analyses showed that a bending beam was perceived as being significantly ($p < 0.01$) more glaring (in terms of discomfort) than a non-bending beam. (See the above text for more details.)
- Methodology: subjective evaluation using de Boer rating
- Type: a bending beam and a non-bending beam
- Scenario: 2 turn directions (left, right)

Bending Beam Further Information

Forward visibility

Diem (2003) conducted a field test comparing three variations of a bending beam system by using subjective brightness and overall acceptance evaluations and eye movement analysis.

Grimm (2001) tested target (40 cm x 40 cm, reflectance =0.08) visibility as a function of curve radius using a prototype dynamic bending beam. For a right-hand curve, the dynamic bending beam increased object visibility. For r=200 m, swivel system detection distance (d) =82 m, for standard system d=52 m; for r= 400 m swivel system d=84 m, for standard system d=61 m; for r=1300 m detection distance nearly equal. Not clear if forward or peripheral visibility study though.

Hamm (2002) conducted a field test to evaluate visibility with an AFS experimental system. A two-lamp asymmetric swivel system was rated as most satisfactory in terms of visibility, followed by the two-lamp symmetric swivel. The one-lamp swivel, though rated as the least satisfactory, was still considered to provide adequate illumination.

Hamm and Rosenhahn (2001) evaluated the feasibility of AFS using prototypes including visibility. The visibility with the HID AFS system gains an earlier detection time of 1.9 s. The results of the subjective evaluations showed that the AFS was more positively rated than an HID system. The authors also compared two sensor systems. One sensor system controlled the angle of the bend through steering wheel angle, and lateral acceleration. The other system was a prediction system using a video sensor and a steering wheel angle sensor. The prediction system always provided the best results for target detection along a curve, especially at the entrance of the curve.

Hogrefe (2000) evaluated three types of bending beams. The systems comprised of static beams alone performed worse, in terms of forward visibility, than the system utilizing the combination movable and static beam. The authors conclude that the static component is beneficial to AFS. The static component is able to illuminate curves of small radii and intersections better than the dynamic bending beam alone. When the dynamic beam alone was the source of illumination, the larger angular rotation required for curves of small radii resulted in a period of time when illumination is reduced in the central direction. However, the dynamic component was necessary to illuminate curves of larger radii.

Ikegaya and Ohkawa (2003) specifically addressed the bending function's ability to illuminate an S-curve (a right-hand curve turning into a left-hand curve). Two evaluations (a computer simulation and a field test) were performed with three systems listed below.

Kobayashi et al. (1999) evaluated an AFS prototype. Each headlamp unit was composed of one main HID headlamp (which rotated) and three additional static bend headlamps. Speed and steering sensors controlled the degree of rotation. Various combinations of the four beam systems were compared in visibility tests with a standard halogen headlamp system. The results of the evaluation indicated substantial improvement over traditional headlamp systems.

Kobayashi and Hayakawa (1991) discussed AFS prototypes and control algorithm. This study also conducted a photometrical analysis on the system performance in terms of illuminance distribution. This study concluded visibility along a curve would be enhanced by the bending beam. No visibility tests were performed.

Neumann (2003) proposed an inexpensive AFS solution using halogen headlamps instead of HID headlamps. A field experiment measured recognition distances of targets on a test track. The study indicated that as target detection became more difficult, the relative effectiveness of the halogen-AFS system increased. The results also suggested that, with the halogen-AFS system, drivers could detect pedestrians 1.8m earlier than with the standard halogen system. This study concluded that the halogen-AFS system can improve visibility by 55% in relation to the standard halogen system. In relation to a standard HID system, the halogen-AFS system demonstrated an improvement in visibility of 23%.

Targets were designated as easy to see ‘E’ (located at straightforward sections), moderate to see ‘M’ (located at the inside and outside bends of moderate curves) and hard to see ‘H’ (located at the inside bends of narrow curves); while driving, subjects indicated through a signal that they detected the target. The results were given as the percentage of targets correctly detected. The results for: Target type E were, 71% and 84%, for standard halogen system and halogen-AFS system respectively; for target type M were 68% and 85%, for standard halogen system and halogen-AFS system respectively; for target type H were 46% and 72%, for standard halogen system and halogen-AFS system, respectively.

The author also performed a test which asked subjects to stop the vehicle when a dummy (mimicking a pedestrian) became visible. While approaching a curve (no radius given) as the test vehicle passed a photosensor trigger, a dummy was simultaneously brought onto the roadway. The vehicle’s speed while approaching the curve was set at 50km/h. Driver reaction time for braking was measured. The measurements show that dummy detection occurred 1.8m earlier with the AFS system vs. the standard system (13.1m and 11.3m for the standard system and the AFS system, respectively).

Sato et al. (2001) evaluated photometric data of a prototype. The authors stated for a right curve the bending beam illuminated 14m further than a standard system. For a left curve the bending beam illuminated 8 m further than the standard system.

Schwab (2003) evaluated target detection with a standard halogen system, a standard HID system, a one-lamp swivel system (ά and 0°), a two-lamp symmetric swivel system (ά and ά), and a two-lamp asymmetric swivel system (ά and ά /2).

Wada et al. (1989) examined eye fixation points while drivers drive curves by using a prototype bending beam. The authors concluded the prototype illuminate the direction in which the driver wants to look, thereby in theory enhancing visibility.

Watanabe et al. (2001) evaluated visibility with a prototype AFS in two ways—subjective evaluation and calculation. The AFS system consistently rated higher than the standard system, though as the curve radius decreased so did the effectiveness of the AFS system. For all curve curvatures, the AFS was always rated one unit better in the five point scale than the standard halogen lamp. The results of the calculation matched with those of the subjective evaluation—the luminance contrast of the target was improved with the AFS.

Eye Fixation

Diem (2003) evaluated eye fixation under the illumination of a standard headlamp system, a one-lamp swivel system, and a two-lamp symmetric swivel system. The results confirmed that eye fixation was a function of illumination distribution.

Hara et al. (2001) investigated found that eye fixation was not always dictated by light distribution. The authors evaluated a standard headlamp system and an AFS headlamp system (no further details provided).

Ishiguro and Yamada (2004) looked at eye fixation during daytime and nighttime. The authors also investigated the effect of vehicle speed on eye fixation behavior.

Wada et al. (1989) concluded that a movable reflector is capable of closely mimicking the driver's eye fixation point around a curved roadway with radius (r) =15m at speeds approximating 30-40km/hr. The reflector demonstrated a distinct lag time (hysteresis) behind the eye fixation point at both the time of entering the curve as well as exiting the curve.

Glare

Grimm (2001) conducted computer simulations to compare glare associated with a standard headlamp system and a swivel headlamp system. Calculations for illuminance at the eye showed that for left-hand curves of radii greater than 150m, a swivel headlamp system would deliver more light to the oncoming driver. The author states despite the increase in illuminance, the light levels were within the tolerance zone under EU regulation 98. For right-hand curves with radii between approximately 30m to 100m, the swivel headlamp system delivers more light to the oncoming driver, with the difference being the greatest between r=60-90 m radii. The swivel system produced approximately 3.35 lx at the eye, while the standard system produced approximately 1.10 lx. The situation reverses with a radius of 110 m, and the standard produced more light at the eye.

Hamm and Rosenhahn (2001) using illuminance measurements compared glare associated with a standard-HID system with two version of an AFS-HID system (see section: 'Forward visibility'). Overall the authors concluded that the AFS systems follow similar patterns of increased illuminance at the eye as the standard-HID system. The authors looked at a right-hand curve (r=250 m) and a left hand curve. Results for the left-hand curve show similar patterns for all three systems with illumination increasing at varied distances. All three systems demonstrated an increase in illuminance periodically at approximately the following distances: 8-10 m, 65-85 m, and 95-110 m. The authors conclude that no more glare will be produced by the AFS systems than is currently seen with standard HID systems.

Right-hand curve results, while demonstrating comparable illuminance levels for all three systems, were different than those found for the left-hand curve. For a right-hand curve, periodicity in illumination was not seen; rather highest illuminance levels were measured towards the nearest distances. The author concluded that differences between left and right-hand curves were function of beam pattern.

Kobayashi et al. (1997) evaluated only a standard halogen headlamps and a standard HID low beam prototype around a curve (r=140m). No subjects were used. Illuminance values were measured at a distance of 100m from the vehicle with the light source, though no indication of methodology is provided (e.g., height of illuminance detector). By using a glare formula developed by Schmidt-Clausen and Bindels (1974), de Boer ratings were calculated assuming an adaptation luminance of 1 cd/m^2. Calculated de Boer ratings were above the 'just acceptable' (rating of 4) except for one condition when the HID prototype was elevated such that the cut-off (assume Japanese beam pattern) was raised 1.5 degrees.

Sato et al. (2001) calculated de Boer ratings for an AFS prototype. For a left-hand curve (Japanese road), de Boer ratings of the prototype always lower (more glaring) than the standard system while, for a right-hand curve, there are little difference between the two systems. For the straights, the prototype was also rated more glaring, by approximately 0.2 in de Boer rating. Over the range of 30 m to100 m, the de Boer rating was 4.1-5.3, and 4.4 -5.5 for the prototype and standard headlamps respectively.

Yamamoto (2004) using computer simulations found that for a left-hand curve (no radius given) a halogen-swivel system (assumed from diagram to be parallel-symmetric) produces no more illuminance at the eye than 2 lx, which the authors state is within the ECE regulation for glare.

5.3.3 Town beam

Automobile forward lighting has to meet two seemingly antithetical requirements: increasing forward visibility and decreasing glare. Therefore, it requires restrictive optical control. However, under certain conditions, e.g., at high ambient illuminances, forward lighting may not be needed for visibility. If forward lighting were dimmable according to traffic density and ambient lighting condition, it would become possible to more efficiently control glare to oncoming and preceding drivers. Table 5.2 summarizes the reviewed studies and their methodologies.

Table 5.2. Town beam methodology summary.
Beam type: E = Europe; J = Japan; NA = North America.

Beam	Study	Dependent Variables	Methodology	Scenario	Subject
NA	Akashi, 2003	target detection distance	standard halogen headlamps dimmed to 10%, 30%, and 100%	static car with moving targets at -15°, -5°, 0°, 5°, and 15°	8, aged 24-33
NA	Birch, 2001	none	none	concept review	none
E	Kalze, 2001	none	none	concept review	none
J	Kobayashi, 1999	stopping distance calculation, subjective evaluation of visibility	comparison of static halogen and three AFS HID systems	4km test course with bends, slopes, intersections, and straights	8
NA	Schreuder, 1975	min and max forward luminous intensity recommendations	literature survey	well-lit city roads	none
E	Worner, 1999	prototype evaluation	three module comparison: basic, side illumination, and spot illumination	town, adverse weather, country roads	none

Town beam main findings

Through the literature survey, the following were identified:

- In lit areas, it is possible to reduce the intensity of forward headlamps to minimize glare to oncoming vehicles while maintaining driver visibility.
- The luminous intensity of the town beam should be higher than 20 cd and lower than 100 cd (to reduce glare to oncoming drivers).

The concept of a town beam, or town light, was proposed in the 1970s. Schreuder (1975) proposed a “city beam” having lower luminous intensity than conventional low beam headlamps and proved that in well-lit areas, headlamps can be dimmed to reduce glare while maintaining drivers’ visual performance. The author addressed the “city beam” concept based on literature from 1950 to 1974. The author concluded that the optimum forward light of motor vehicles to be used on lit roads should have an intensity that is lower than present low beam headlights, but higher than sidelights. When road lighting is present (even very poor road lighting), low beam headlights make only a small and mostly negligible contribution to illumination, and thus to the visibility of objects. It was suggested that the minimum luminous intensity should be at least 20 cd, and the maximum not more than about 100 cd to reduce glare to oncoming drivers. However, it might be difficult to apply the “city beam” concept to automotive practice in the 1970s for technical reasons. Recent AFS technology may spur the realization of the “city beam” concept.

Recently, many studies on AFS have proposed the concept of a town light, similar to Schreuder's "city beam." In the Eureka Project EU 1403, the town light is defined as a forward light for restricted speed with high traffic density on roadways and pedestrians on sidewalks (Eureka, 2002). Birch (2001) suggested that in lit areas where vehicle speed is relatively low, the high intensity spots of headlamps are unnecessary and therefore can be turned off. Such a low intensity beam distribution could reduce glare to oncoming drivers in lit areas (Kalze, 2001). Figure 5.9 compares forward headlamp patterns for a town light and a country light in such an AFS. These adaptive headlamps are achievable by a dimming controller in conjunction with a photosensor system. Among those conceptual discussions, a few studies addressed illuminance requirements. Kobayashi et al. (1999) specified forward lighting for a town light, requiring 10 lx at a distance of 50 m. Birch (2001) specified that the maximum range of illumination (1 lx) for a town light be less than 60 m.

Although the concept is already well established (Worner, 1999; Kobayashi et al., 1999), few field studies have investigated how the adaptable forward headlamp system functions in practice or how the system influences driver performance. A series of controlled field studies were conducted to examine these issues. The first field study investigated how vehicle headlamps contribute to drivers' target detection in lit areas, and therefore how headlamps interact with fixed roadway lighting (Akashi et al., 2003). Figure 5.10 shows the results of the experiment. The results of this study showed a consistent tendency: The detection distance of targets increased as roadway illuminance increased. However, headlamps did little to improve target visibility as headlamp intensity increased. The results implied that to reduce the impact of headlamp glare for oncoming drivers, the headlamp intensity could be dimmed without greatly impairing target visibility in lit areas. The second field study investigated interactions between ambient roadway lighting, forward headlamps, and oncoming glare. This study explored whether and how oncoming headlamp glare impaired drivers' target detections under a lit ambient condition, and whether forward headlamps help drivers detect targets when oncoming glare exists. Figure 5.11 shows the results of the study. Figure 5.11 suggests that oncoming glare can reduce detection distance by up to 30 m; therefore, it is useful to dim forward lighting to reduce glare to oncoming vehicles in lit areas.

The literature suggests that town lights may be an effective way to reduce glare. However, to verify the validity of the town light, it is still necessary to identify the appropriate luminous intensity distribution for the town light and conduct field studies on real roadways using a town light prototype.

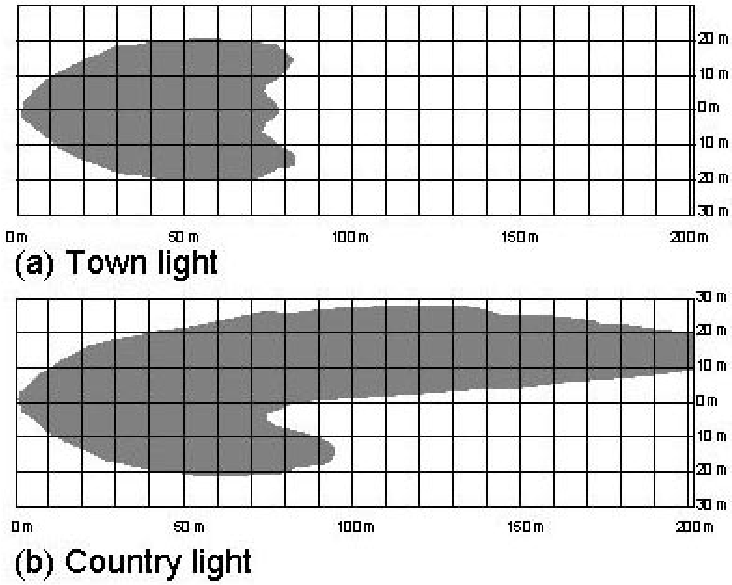


Figure 5.9. Beam patterns of an adaptive forward headlamp system (after Kalze, 2001).

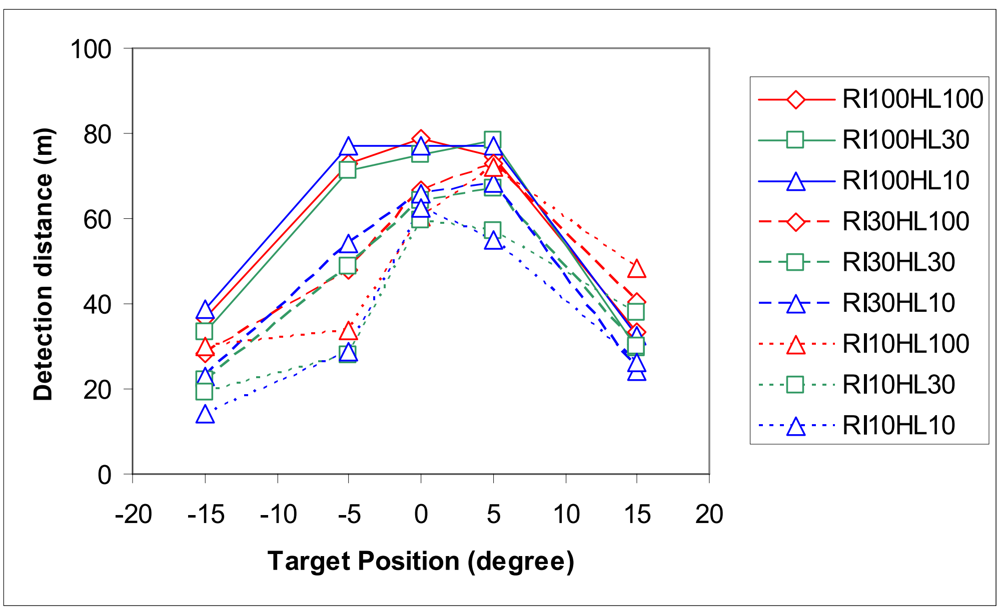


Figure 5.10. Results of detection distance.
RI: ambient roadway illuminance (%), HL: headlamp intensity (%)
(after Akashi et al., 2003)

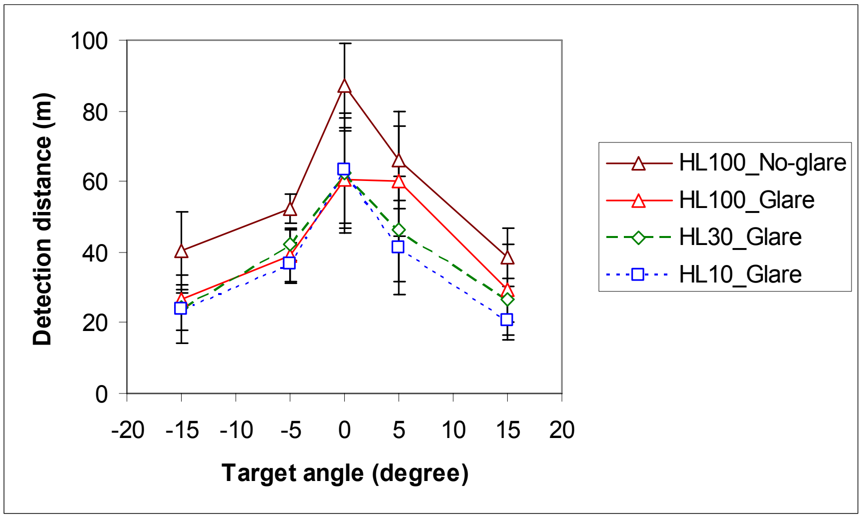


Figure 5.11. Results of detection distance with oncoming glare.
HL: forward lighting (%), Glare or No-glare: with or without oncoming glare
(after Akashi et al., 2003).

Town Beam Key References

Summaries of the reviewed studies are listed below in chronological order. Short descriptions of methodology, bending beam types, and scenarios are also listed.

Akashi et al. (2003) conducted a field study to investigate how vehicle headlamps contribute to target detection in lit areas and therefore how headlamps interact with fixed roadway lighting.

- Methodology: field study
- Subject: eight, ranging 24 to 33 in age
- Type: standard halogen headlamps (dimmed in to 100, 30, and 10 %)
- Scenario: town light

Schreuder (1975) proposed a concept of "city beam" based on survey on literature from 1950s to 1974. It is suggested that the minimum luminous intensity should be at least 20cd, and the maximum not more than about 100cd. The upper limit of the luminous intensity, 100cd, of the "city beam" was considered based on the level of admissible glare.

- Methodology: literature survey
- Type: town light
- Scenarios: well-lit city roads

Town Beam Further Information

Birch (2001) addressed a town light among five types of AFS functionalities; others include motorway light, country light, adverse weather light, and bending beam. The town light was defined as a symmetrical beam pattern with a sharp cutoff and very small forward rake angle is the best approach. It was also mentioned dazzling the traffic in front should be as little as possible.

Kalze (2001) addressed an AFS concept. The headlamp system is composed of a basic light module (left and right headlamp), high beam, and static bending beam to provide a comfortable compromise between visibility distance, reduced glare to oncoming traffic, and illuminance uniformity. In town light mode, the basic light modules have symmetrical cutoff line geometry. Depending on speed, the modules are swiveled.

Kobayashi et al. (1999) specified town light requirements in terms of stopping distance. The authors also evaluated an AFS prototype; each headlamp unit was composed of one main HID headlamp (which rotated) and three additional static bend headlamps. The results of the evaluation indicated substantial improvement over traditional headlamp systems.

Worner (1999) provided AFS concepts including town light.

5.3.4 Motorway beam

The aim of a motorway beam, or a motorway light, is to provide the longest range of vision ahead to drivers while minimizing glare to oncoming traffic. Like the bending beam, motorway light functionality has already been addressed in many articles. Eight papers were reviewed on this subject: Birch (2001), Damasky and Huhn (1997), Hamm and Rosenhahn (2003), Rosenhahn and Hamm (2003), Hogrefe and Neumann (1997), Kobayashi et al. (1999), Manassero et al. (1998), Sivak et al. (2001). Table 5.3 summarizes the reviewed studies and their methodologies.

Table 5.3. Motorway beam methodology summary.
Beam type: E = Europe; J = Japan; NA = North America.

Beam	Study	Dependent Variables	Methodology	Scenario	Subject
NA	Birch, 2001	none	none	concept review	none
NA	Damasky and Huhn, 1997	minimum forward illuminance recommendation	statistical analysis on videotaped drivers' forward views	urban and country roads, motorways	none
NA	Hamm and Rosenhahn, 2003	small target detection	stationary evaluation of motorway light prototypes	straight motorway	11
E	Hogrefe and Neumann, 1997	none	none	concept review	none
J	Kobayashi, 1999	stopping distance calculation, subjective evaluation of visibility	comparison of static halogen and three AFS HID systems	4km test course with bends, slopes, intersections, and straights	8
E	Manassero et al., 1998	target detection	motorway beam comparison for contrast sensitivity calculation	motorway	?
NA	Sivak et al., 2001	illuminance calculations	calculations used mean market-weighted intensity distributions, both US and European beam patterns	motorway, curves	none

Motorway beam main findings

Through the literature survey, the following conclusions were made:

- Motorway light functionality can be ideally achieved by adding a static beam component to increase the central visual field. It is also possible to simply tilt up the conventional high beams by 0.25° to 0.5°. For the tilting approach, European beams may be more effective than US beams.
- The requirements targeted by manufacturers for the motorway light are 120-200 m in beam throw distance and 3-5 lx in illuminance, which are based on stopping distance and contrast sensitivity calculations, respectively.
- Field studies using AFS prototypes found that the motorway light improved driver visibility and satisfaction.
- However, from the literature survey, it was difficult to determine whether a motorway beam can improve traffic safety or how wide and far a headlamp beam should illuminate as a function of speed.

These studies are categorized as (1) conceptual design, (2) beam specification, and (3) feasibility evaluation. The first group, conceptual design, addressed conceptual beam patterns for the motorway light among other AFS functionalities (Birch, 2001; Damasky and Huhn, 1997; Hogrefe and Neumann, 1997). For instance, Birch (2001) claimed that a symmetrical beam pattern with a sharp cutoff and very small forward rake angle was the best approach to motorway lighting. However, production of glare to oncoming cars should be minimized. Besides depicting iso-illuminance contours of prototypes, these authors did not specify the detailed target requirements or specifications for the motorway light.

The second category, beam specification, included two studies attempting to identify lighting requirements. To determine appropriate beam patterns for several scenarios (e.g., urban roads, country roads, adverse weather roads, and motorways), Damasky and Huhn (1997) videotaped forward roadway views and analyzed potential positions of important targets such as traffic signs, delineation reflectors, and preceding cars. Based on the probability of emergence of those important targets for each scenario, a minimal illuminance requirement was determined. Motorway light functionality needs to consider large viewing distance, optimal optical guidance, traffic sign illumination, and less glare for other road users. Figure 5.12 shows the resulting motorway beam pattern from this study.

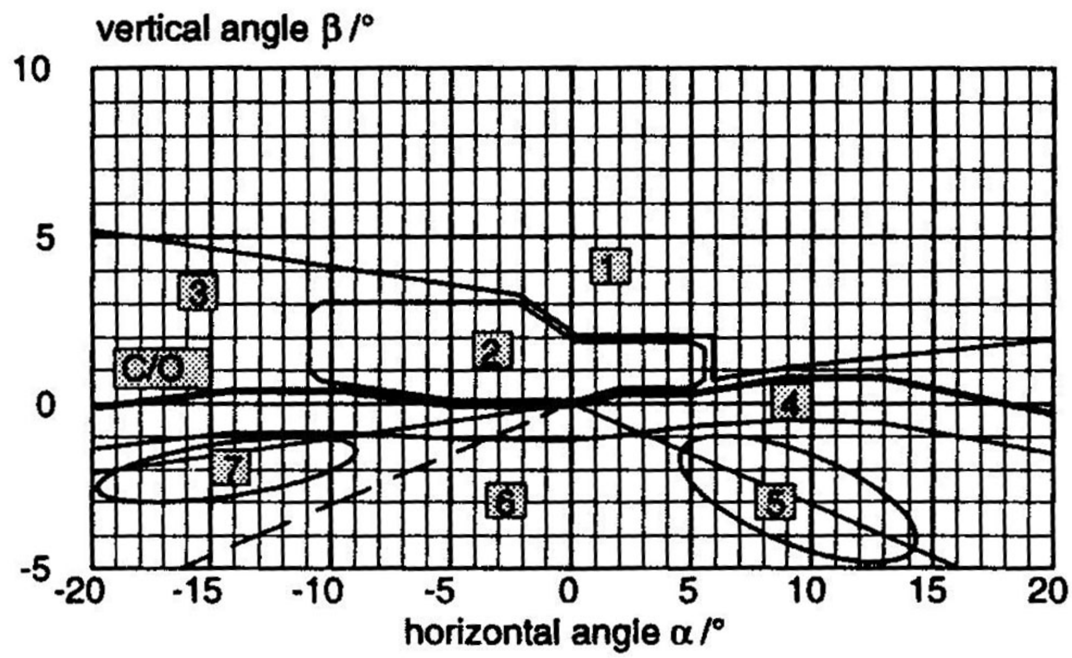


Figure 5.12. Motorway light distribution (after Damasky and Huhn, 1997).
Zones and illuminance measured on a screen, 25 m away: 1. overhead signs: E<2 lx, 2. glare area: E<1 lx, 3. shoulder mounted signs: E< 1.5 lx, 4. fixation area: 25 lx <E< 100 lx, 5. foreground right: E>15 lx, 6. fore ground center: 5 lx <E< 25 lx, 7. foreground left: E>15 lx.

To determine an appropriate motorway beam pattern, Kobayashi et al. (1999) used another method, the stopping distance calculation. Stopping distance is the minimum distance at which drivers have to detect targets in order to stop without colliding with the detected targets (e.g., obstacles on the roadway or peripheral animals that are about to jump into the roadway). Table

5.4 shows the resulting design goals for the motorway light in terms of beam throw distance and illuminance. Unfortunately, the authors did not provide enough information for readers to understand how the authors determined these illuminance and beam throw requirements.

Table 5.4. Design goals for basic beams (after Kobayashi et al., 1999).

Beam pattern	Driving speed (km/h)	Stopping distance (m)	Illuminance (lx)	Beam reach (m)
Motor light	100	112	5	120
Country light	80	76	5	80
Town light	50	32	10	50

The other study in this category used a more fundamental approach to identify requirements for the motorway light. Manassero et al. (1998) conducted a fundamental study using a screen located at a distance of 25 m from a subject who sat in a test car. At various locations on the screen, targets with various luminance contrasts and spatial frequencies were presented. As soon as the subject detected one of the targets, he or she signaled the detections to an experimenter. The target locations corresponded to lateral positions of signs, pedestrians, lane markings, and generic obstacles on the lane at different distances. Based on the fundamental data collected through the experiment, the authors identified AFS lighting requirements, as shown in Table 5.5. Despite different methodologies, interestingly there were few conflicts in illuminance requirements between the three studies.

Table 5.5. Road illumination requirements for an adaptive lighting system.

<table>
<tr><th>Devices</th><th>Beam patterns</th><th>Visibility on straight (m)</th><th>Visibility on curve r=150m (m)</th><th>Illuminance (lx)</th><th>Angular window for specified visibility (deg.)</th></tr>
<tr><td rowspan="2">Conventional beam</td><td>Low beam</td><td>58</td><td>30</td><td>40</td><td>--</td></tr>
<tr><td>High beam</td><td>140</td><td>--</td><td>120</td><td>--</td></tr>
<tr><td rowspan="3">AFS</td><td>Country</td><td>80</td><td>--</td><td>20</td><td>Hor.: -1° to 1°
Ver.: -0.75° to 0.3°</td></tr>
<tr><td>Bending</td><td>--</td><td>76</td><td>6</td><td>Hor.: -4° to 35°
Ver.: -1° to -0.5°</td></tr>
<tr><td>High speed</td><td>200</td><td>--</td><td>3</td><td>Hor.: -1° to 1°
Ver.: -0.3° to 0°</td></tr>
</table>

In the third category, feasibility evaluation, calculations and field studies were used to evaluate motorway beams. There are three studies: Hamm (2002), Kobayashi et al. (1999), and Sivak et al. (2001). Hamm (2002) conducted a field test to evaluate the function of a motorway beam provided by an AFS prototype compared to standard halogen and HID beams. In the field test, subjects detected targets (20 cm × 20 cm, reflectance=10%) located along a street. The results showed that detection distance with the motorway beam pattern was 148 m compared to 70 m and 85 m for the halogen and HID low beams, respectively. The authors conducted another field test in which 53 volunteers drove a test car equipped with the AFS prototype. The subjects rated their degree of satisfaction for the driving experience with the AFS prototype using a nine-point scale (1=unsatisfactory; 9=optimal). The results suggested that with regard to satisfaction, the motorway function was rated as a value of 8.6 compared to 7.4 and 8.0 for town light and cornering light, respectively. The 53 volunteers also were asked how each of the AFS functions, including bending, cornering, motorway, and town beam, is important for them. The results showed that the motorway beam was considered as an important function was ranked as No. 1, function by 44% of frequent travelers.

Kobayashi et al. (1999) also conducted a field test to evaluate the performance of an AFS prototype. Each headlamp unit was composed of one main HID headlamp (which rotated) and three additional static bend headlamps. Various combinations of the four beam systems were compared in visibility tests with a standard halogen headlamp system. In the study, eight subjects drove a test course and evaluated the performance of the prototype by using a 10-point visibility scale (0=unacceptable to 10=very comfortable driving). The results of the evaluation indicated substantial improvement for the AFS prototypes in various scenarios over conventional headlamp systems. By adding a supplemental beam as a high speed motorway light when automobile speed exceeded 100 km/h, visibility evaluation improved from 6.1 to 7.6 in the 10-point scale.

Sivak et al. (2001) evaluated illuminance distribution of the motorway light using standard (non AFS) headlamps from the US and European mean market-weighted model (year 2000) beam patterns. To simulate highway light, the authors vertically shifted those market-weighted beam models 0.25° and 0.5° up. The results indicated that both the US and European beams shifted upwards resulted in increased illuminance, and therefore increased visibility for a variety of targets. However, increased vertical illuminance may also increase glare to oncoming traffic. The 0.25° shift resulted in less increase in glare (28% for the US beam and 18% for the European beam) than the 0.5° shift. Because of the relatively steeper vertical gradient of the European beams, the relative visibility benefit due to shifting the beam upward is greater for the European beams. Nevertheless, the European beams at the 0.25° shift delivered lower illuminance on several targets than the nominally aimed US beams.

To investigate an appropriate beam pattern for a motorway beam, Damasky and Huhn (1997) videotaped roadway scenery in a few scenarios and analyzed locations of objects that should be visible to drivers. Such an approach should be applied to other scenarios to optimize beam distribution for the motorway beam because its intense directional luminous distribution may cause glare to a vehicle that happens to be in the beam.

Motorway Beam Key References

Summaries of the reviewed studies are listed below in chronological order. Short descriptions of methodology, motorway beam types, and scenarios are also listed.

Damasky and Huhn (1997) addressed beam patterns for urban roads, country roads, and motorways. To determine appropriate beam patterns for those road types, the authors first videotaped forward roadway views and analyzed potential positions of important targets such as traffic signs, delineation reflectors, and proceeding cars. Based on the probability of emergence of those targets for each roadway type, a minimal illuminance requirement was determined.

- Methodology: videotaped scenery, probability of important target emergency
- Scenarios: urban beam pattern, country road, motorway, and adverse weather lighting.

Hamm and Rosenhahn (2003) and Rosenhahn and Hamm (2003) evaluated the feasibility of AFS using prototypes including visibility. The study used target detection distance as a criterion.

- Methodology: target detection (20cm x 20cm ρ=0.1) placed on the right edge of a straight.
- Subjects: 11 (stationary).
- Types: motorway light.
- Scenarios: straight motorway.

Sivak et al. (2001) examined the potential benefits of applying two embodiments of adaptive lighting to the US and European low-beam patterns. The motorway lighting was simulated by shifting the US and European low-beams 0.25 and 0.5 degrees up.

- Methodology: calculation of illuminance at distances from 20-100 m using mean market-weighted beam luminance intensity distributions
- Types: motorway light
- Scenarios: motorway (and curves)

Motorway Beam Further Information

Birch (2001) addressed motorway light among five AFS functionalities; others include town light, country light, adverse weather light, and bending beam. The motorway light was defined as a symmetrical beam pattern with a sharp cutoff and very small forward rake angle is the best approach. It was also mentioned dazzling the traffic in front should be as little as possible.

Hogrefe and Neumann (1997) reviewed AFS concepts. Town, country, motorway beam patterns explained. Beam pattern changing technology reviewed, and controls: a distinction is made between direct automatic control and more sophisticated predictive controls.

Kobayashi et al. (1999) addressed appropriate beam distribution based on stopping distance calculation. Based on the analyses, the authors proposed forward lighting requirements for AFS functions including motorway light, country light, town light, and bending beam. The authors also evaluated performance of each function by using a prototype. The results of the evaluation indicated substantial improvement over traditional headlamp systems.

Manassero et al. (1998) conducted a fundamental study to determine appropriate beam distribution in terms of contrast sensitivity.

5.3.5 Adverse weather light

Rain, snow, fog, and wet roadway surfaces dramatically alter the visibility of a driver. Under such adverse weather conditions, drivers have difficulties in seeing traffic flows and detecting potential hazards. Rain, snow, and fog increase the background luminance, reducing the visibility of drivers. Water on the pavement increases forward reflection while reducing backward reflection, resulting in glare to oncoming vehicles and a reduction in roadway luminance for drivers. The adverse weather reduces the luminance contrast of a target against the background and therefore drivers' forward visibility. Adverse weather beams, or adverse weather lights, have been proposed to solve those problems, thereby increasing driver visibility. Table 5.6 summarizes the reviewed studies and their methodologies.

On rainy days, another factor affecting visibility is a layer of water on a windshield. No research has been conducted to identify lighting solutions of scattered light caused by the water layer. This report does not discuss this subject.

Table 5.6. Adverse weather light methodology summary.
Beam type: E = Europe; J = Japan; NA = North America.

Beam	Study	Dependent Variables	Methodology	Scenario	Subject
NA	Birch, 2001	none	None	concept review	none
E	Dietz, 1997	fog luminance	fog luminance calculations for normal headlamps using Monte Carlo method	various fog densities, headlamp mounting heights	none
E	Frieding, 1999	road luminance calculations, subjective evaluations of visibility	rain light prototype evaluation?	80 km of highways, motorways, and country roads, dry and wet	?
E	Kalze, 2001	none	none	concept review	none
NA	Rosenhahn, 1999	glare illuminance, threshold luminance	calcuations for HID and halogen headlamps	straight roadway, dry and wet	none
NA	Rosenhahn, 2001	fog luminance calculations, subjective evaluation of visibility	fog luminance calculations for fog lamps using Monte Carlo method	various fog densities	none
E	Schien, 2003	none	ECE and SAE fog regulations comparison	none	none
E	Schwab, 1999	illuminance measurement, probability analysis	comparison of standard HID and halogen headlamp systems	straight roadway, dry and wet	none
E	Von Hoffman, 2003	subjective evaluation of discomfort glare	comparison of divergent swiveling HID headlamp system with a parallel swiveling system: lab measurements of road sample reflective properties, field measurements, rating test	test ground with curves, dry and wet	60

Adverse weather light main findings

Several studies proposed headlamp beam patterns for adverse weather conditions. However, how those beam patterns were determined is not described and how much those beam patterns can improve forward visibility is not yet investigated. Through the literature survey for adverse weather conditions, the following conclusions were identified, in theory:

- Provide high intensity light at the outward edge of a road in a distant zone.
- Illuminate the road edges on both sides of a road.
- Reduce light intensity in the immediate frontal zone.

However, it is still unknown how wide and short a headlamp beam should be under adverse weather conditions.

Based on an experiment for snowplow drivers, the LRC established a simple model to predict forward visibility in a perturbed atmosphere, i.e., falling snow, rain, and fog, at night. The model suggests that to improve forward visibility under perturbed atmosphere conditions, it is important to increase the intensity of light, narrow the beam width, and increase displacement of the light source from the line of sight.

Reflection on wet surfaces

Weather conditions dramatically change the reflective property of road surfaces. Water on the pavement increases forward reflection while reducing backward reflection. The increase in forward reflection increases glare to oncoming drivers. The luminance contrast of a target compared to the background is reduced, and therefore the target visibility is reduced if the target reflectance is lower than the pavement reflectance.

Freiding (1999) found differences in road luminance between dry and wet pavement surfaces. For instance, the wet road surface reaches the maximum luminance at a distance of 30 m compared to 40 m for the dry road condition (Figure 5.13). The higher luminance with the wet surface causes more severe glare to oncoming drivers, exceeding the permissible illuminance of 0.25 lx by more than one log unit. Rosenhahn (1999) measured glare illuminances and threshold luminances comparing HID and halogen headlamps under a wet road condition. Figure 5.14 shows illuminance at drivers' eyes, comparing a halogen reflection system and an HID projection system. These findings define a goal for the adverse weather light to reduce exposure of oncoming drivers to glare sources.

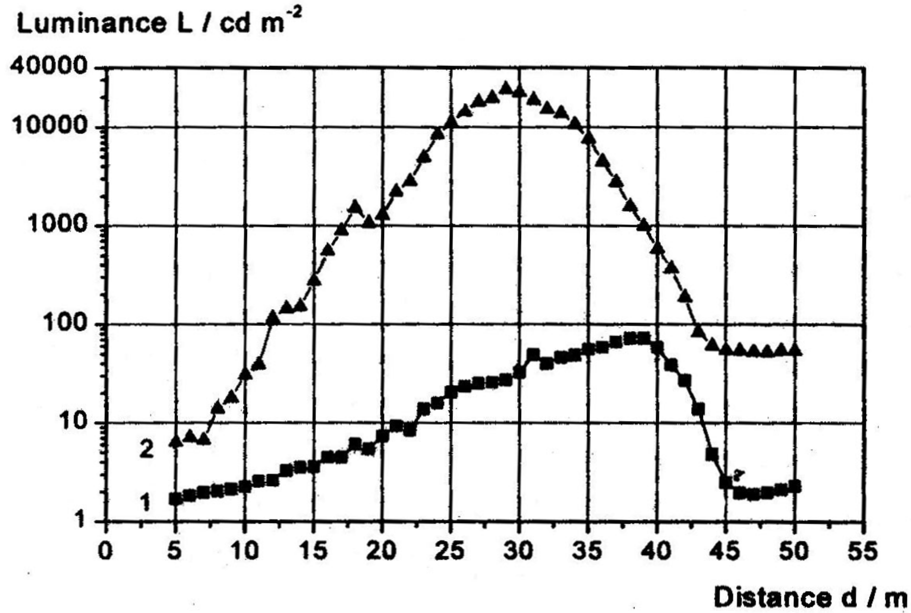


Figure 5.13. Mean value of glare luminance of both headlamps, observed from the drivers' eye position at distance d=0m, d=50m. 1: dry, 2: wet road condition (after Freiding, 1999).

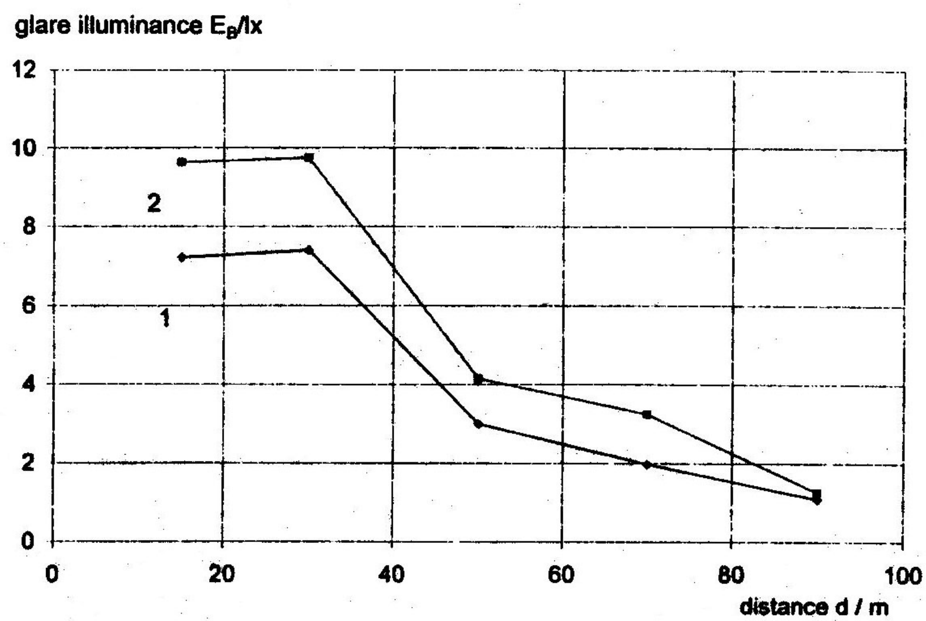


Figure 5.14. Illuminance at drivers' eyes for wet condition as a function of distance. 1: dry, 2: wet road condition (after Rosenhahn, 1999).

To reduce glare caused by light reflection on wet surfaces, Freiding (1999) proposed a modular designed beam distribution composed of six zones (Figure 5.15). In Figure 5.15, Zone 1 extends the cutoff line and forms a basic illumination that corresponds to a traditional low beam. Zones 2 and 3 represent short-distance side illumination. The long-distance area is formed by Zones 5, 6, and a part of Zone 1. Zones 5 and 6 allow additional illumination of the right and left rim of the road for longer distances, over 18 m.

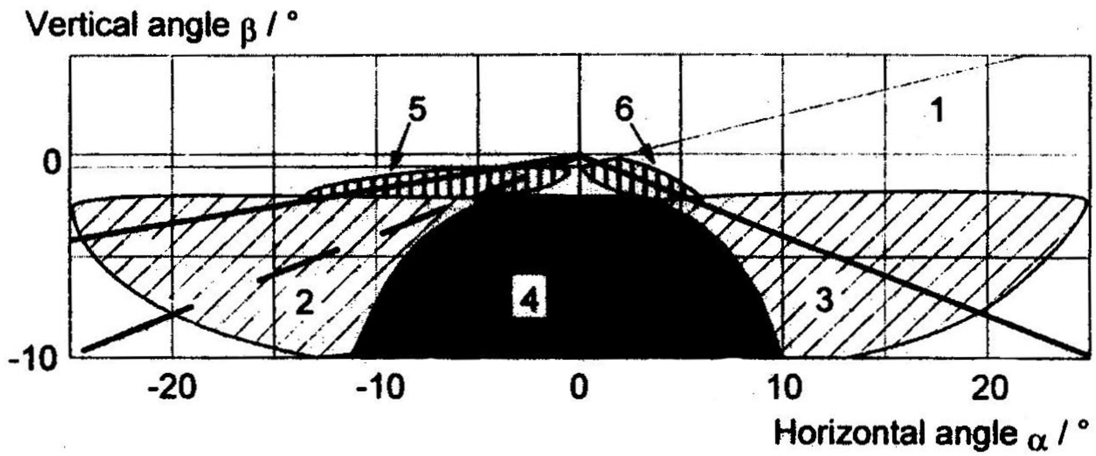
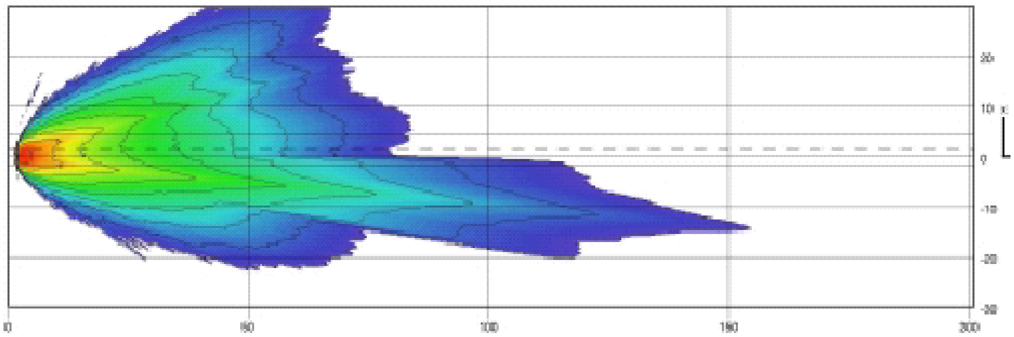


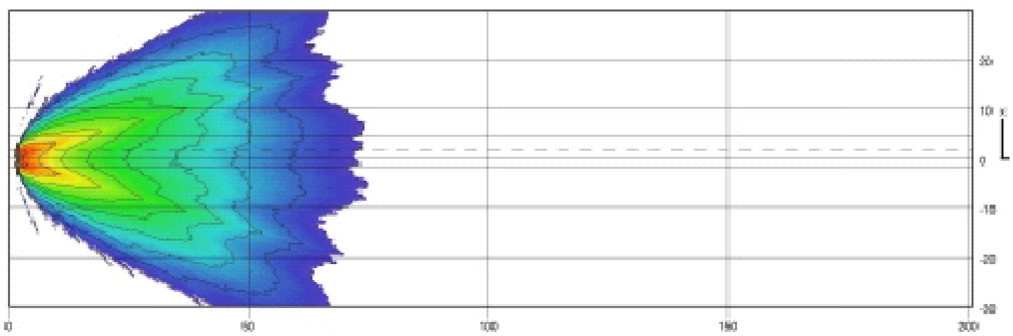
Figure 5.15. Schematic illustration of modular designed light distribution (after Freiding, 1999).

Kalze (2001) also illustrated adverse weather light distributions (although the author did not provide any background data). Figures 5.16 (a) and (b) show headlamp beam distributions for normal rain and heavy rain conditions, respectively. In normal rain (Figure 5.16 (a)), to reduce reflection on the roadways, the distribution is changed into a divergent mode with a horizontal angle of 15°. Additionally, to maintain driver visibility, the right headlamp provides motorway light toward the right side of the roadway with a horizontal angle of 5°. In heavy rain (Figure 5.16 (b)) the light distribution is changed into the maximum divergent mode with a horizontal angle of 30° without the motorway light. The resulting beam pattern looks similar to the town light. The reflection glare is reduced to a level of nearly 30% of the standard beam pattern.

Rosenhahn (1999) also designed a beam to reduce illuminance within a specific angular zone. It produces less glare for oncoming vehicles while still allowing the driver to see. The author developed a prototype based on the above described findings. The results of the evaluation suggested that glare illuminance was reduced by 52% in the critical zone, the contrast sensitivity was decreased, and re-adaptation time was decreased.



(a) For rain with a wet road



(b) For heavy rain

Figure 5.16. Adverse weather light distribution for rain and wet roadway surfaces (after Kalze, 2001).

Fog

The luminance contrast of a target to the background is reduced by light scattered by fog particles in two ways—increasing the background luminance and reducing the target luminance. While light goes through the fog, it reflects on fog particles and scatters in every direction. The scattering light increases the adaptation luminance that reduces the luminance contrast of objects to the background, making target detection more difficult. Few articles directly study AFS fog beams, but a couple of studies have addressed the question of how a perturbed atmosphere impairs drivers' forward visibility. The solution these studies suggest is to increase the displacement of forward headlamps from the line of sight as much as possible.

The LRC proposed a simple model, shown in Equation 1, to predict forward visibility (V_F) in a perturbed atmosphere, i.e., falling snow, rain, and fog, at night (Bullough and Rea, 1997). This study found that through snow or fog, forward visibility is proportional to the flux produced by a lamp and inversely proportional to its field angle (and, therefore proportional to the maximum intensity, I_{max} in cd) and proportional to the displacement (d, in m) from the line of sight.

$$V_F = I_{\max} d \qquad (1)$$

Rosenhahn (2001) used a computer simulation program to predict the luminance distribution of scattered light originating from forward headlamps in fog, developed by Darmstadt University of Technology. Figure 5.17 shows the results of the calculation. The results suggested that the left headlamp causes a larger amount of scattering light than the right headlamp. This is because the drivers' eyes are closer to the left headlamp than the right one. Similar results were found by Dietz (1997).

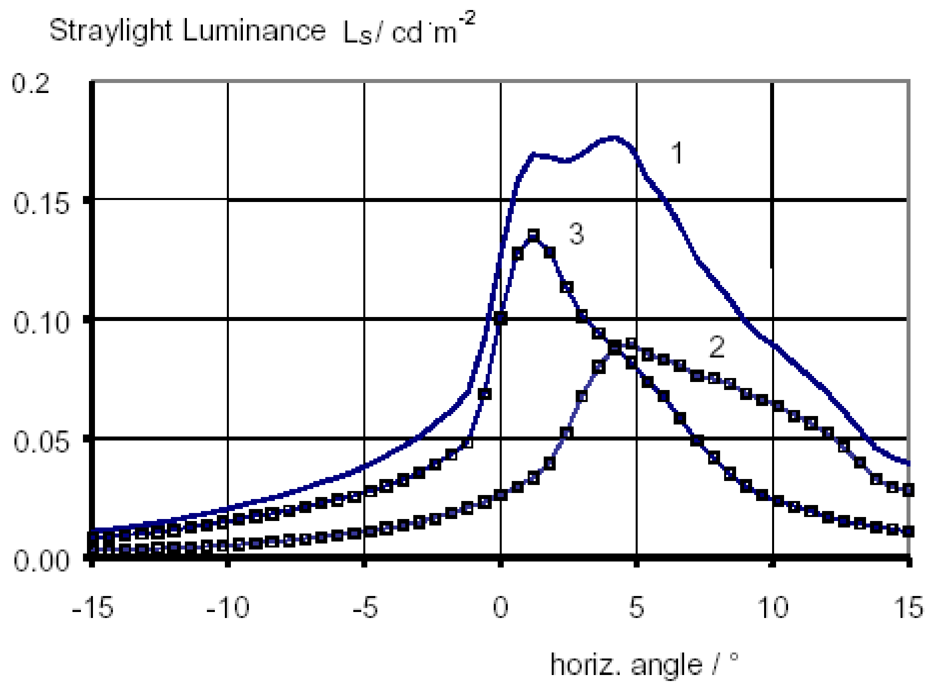


Figure 5.17. Distribution of luminance caused by a headlamp system. 1: with both side headlamps, 2: with right headlamp, 3: with left headlamp (after Rosenhahn, 2001).

Rosenhahn (2001) also investigated the effect of cutoff lines on fog luminance for various headlamp inclinations and fixation distances. Figure 5.18 shows the results of the calculation. Figure 5.18 suggests that the fog luminance decreases as the headlamp inclination increases. This leads to an idea that the inclination of a front fog lamp should be changed according to the thickness of fog.

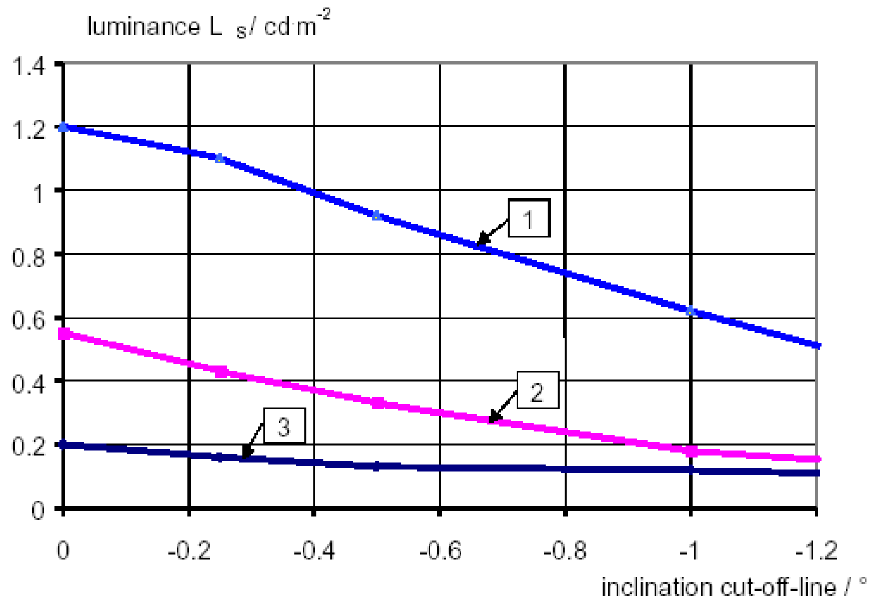


Figure 5.18. Fog luminance distribution as a function of aiming position, for a visibility distance of 50 m (after Rosenhahn, 2001).

Kaltz (2001) proposed a fog light distribution (Figure 5.19). The author stated that since a driver's attention should be led to the boundaries of the street, high intensities are needed toward the two directions.

Based on fog luminance calculation and evaluations, Rosenhahn (2001) proposed a recommendation for a fog headlamp distribution. Figure 5.20 shows the proposed inclination for forward headlamps as a function of visibility distance. The author recommended an asymmetric distribution for below the cutoff line in which the left headlamp has a lower maximum than the right. Above the cutoff line, stray light should be carefully controlled according to the fog condition. The author also proposed five inspection points, as shown in Figure 5.21. Those five points are critical points where luminous intensity should be restricted.

According to the above described study (Bullough and Rea, 1997), such wider beam distributions can increase scattered light. Therefore, the wider beam distributions will need a more critical adjustment of inclination. Since few studies confirm if those beams work on practical roadways, it is necessary to conduct field studies for the verification of adverse weather beams.

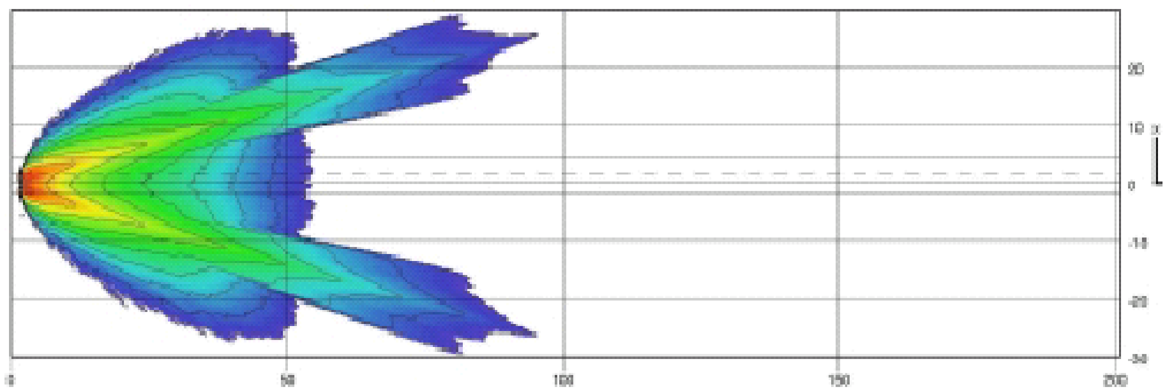


Figure 5.19. A fog light distribution (after Kaltz, 2001)**.**

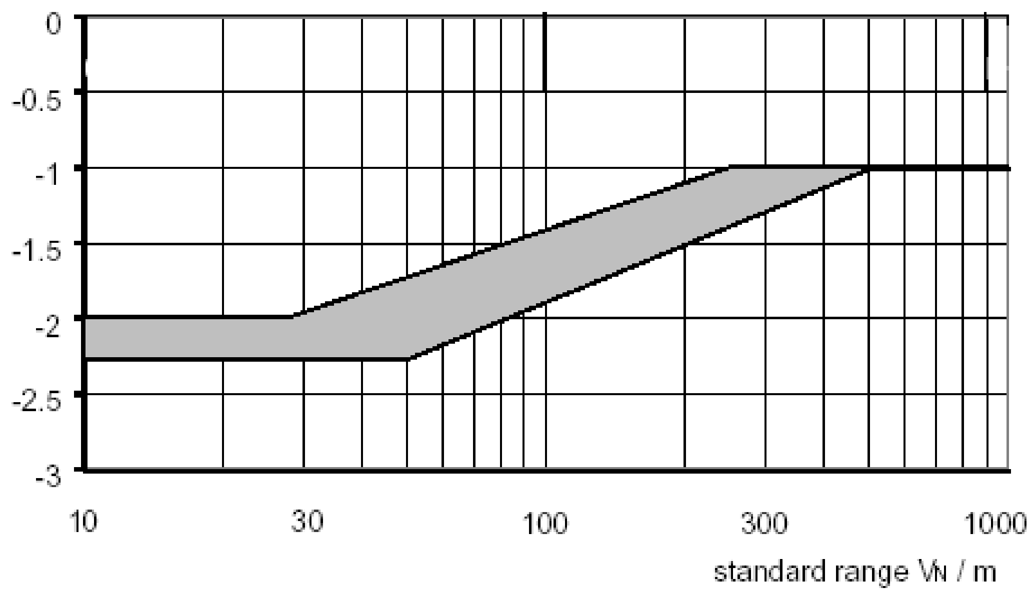


Figure 5.20. Proposed headlamp inclination angle as a function of visibility distances of fog. The vertical axis represents inclination angle of headlamps (after Rosenhahn, 2001).

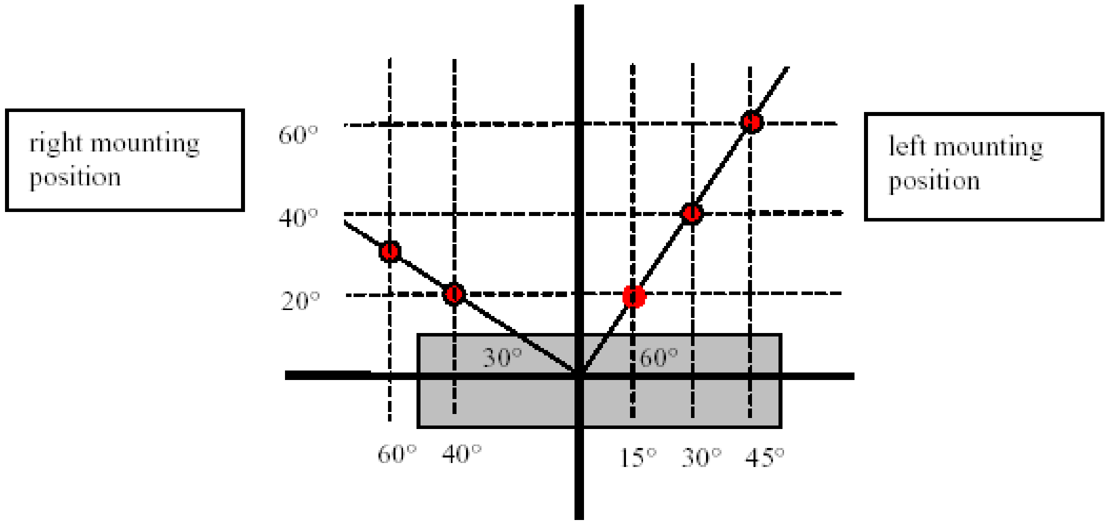


Figure 5.21. Proposed measurement points to restrict the luminous intensity (after Rosenhahn, 2001).

Adverse Weather Key References

Frieding (1999) calculated maximum acceptable road luminance under various pavement conditions, from dry to wet. Under wet conditions, reduced luminance (25% and 50% of the dry) in the central roadway zone was still deemed "acceptable", purportedly due to decreased adaptation luminance. However, on side land markers for orientation, desired luminance was increased to 180% on the left and 220% on the right. Evaluations took place on 80km of country road, federal highway, and motorway.

- Methodology: calculation and subjective evaluation.
- Types: rain light.
- Scenarios: wet surfaces on country roads, highways, and motorways.

Rosenhahn (1999) measured glare illuminance and threshold luminance for HID and halogen headlamps in wet road conditions for a wide range of distances.

- Methodology: calculation of glare illuminance
- Type: adverse weather light
- Scenario: a straight roadway in dry and wet conditions

Rosenhahn (2001) calculated fog luminance distribution under various conditions. The author also proposed a recommendation for fog light adjusted according to fog density.

- Methodology: calculations and subjective evaluations
- Type: fog light
- Scenario: fog with different density

Adverse Weather Further Information

Birch (2001) addressed adverse weather light among five AFS functionalities; others include town light, country light, motorway light, and bending beam. To reduce reflection on the wet road causing dazzle to oncoming drivers, the adverse weather light should reduce the level of illumination in the immediate frontal zone, up to about 20m in front of the vehicle, to an acceptable level by oncoming traffic.

Dietz (1997) used a calculation tool of fog luminance developed by Boehlaw-Godau and Rosenhahn (1995) based on the Monte-Carlo method. This study calculated fog luminance caused by a headlamp system comparing headlamp location (left and right), different mounting heights, and different fog densities.

Kaltz (2001) addressed an AFS concept. The headlamp system is composed of a basic light module (left and right headlamp), high beam, and static bending beam to provide a comfortable compromise between visibility distance, reduced glare to oncoming traffic, and illuminance uniformity. In night rain situation, the left basic light module generates a horizontal cutoff line and is forces into divergent mode with an angle of 15 degrees. The right module generates the motorway cutoff line with divergent mode of 5 degrees. This beam patter can reduce reflex glare to the oncoming traffic.

Rosenhahn (2003). This article is almost identical to the one in 2001 (Rosenhahn, 2001).

Schien (2003) compared new legal requirements with the existing regulations for ECE and SAE. Different front fog lamp designs that meet these new regulations are shown. An important aspect is the possibility of combining the front fog lamp function and the cornering lamp function.

Schwab (1999) measures illuminance distribution at different distances along a real straight roadway comparing between two surface conditions (wet or dry) and between two headlamps (HID and halogen).

Sullivan and Flannagan (1999) used 11 years of fatality data to assess the light sensitivity of different scenarios (intersections and curvy roads). Dividing the analysis into day, night, and twilight time zones, they found a seasonal sensitivity to light in the twilight zone.

Von Hoffmann (2003) discussed adverse weather light function. In order to determine criteria to design these AFS functions, laboratory measurements of reflective properties of road samples and field measurements on a test ground were conducted. A rating experiment with 60 test persons under dry and wet road conditions suggested that a divergent swiveling headlamp system caused smaller glare to oncoming drivers on wet roadway surfaces than a parallel swiveling system.

5.3.6 Regulations

Forward lighting regulations, which secure traffic safety, might have prevented new AFS technologies from being implemented earlier. In the 1950s, for instance, the Citroen was already equipped with swiveling headlamps. However, due to legal restrictions in Europe, the function was applied only to high beams. The low probability of high beam operation did not encourage other manufacturers to follow this unique approach.

Regulations main findings

The Eureka Project examined ways to introduce AFS technology after confirming its potential contribution to the improvement of traffic safety. In order to introduce AFS technology to Europe, regulations within ECE-WP.29 had to be modified. Two amendments were introduced that allow AFS to be officially released in Europe in two stages. The first stage, approved in March 2003, allows automobile low beam headlamps to be swiveled. The second stage is forecast for approval in 2005. This stage will include situation-related functions such as motorway, town, and cornering lighting. Current ECE draft regulations, TRANS/WP.29/GRE/2002/ 18, 19, and 20, specify low beam photometric provisions for the following classes: (1) Class C (basic) beam, (2) Class V (town) beam, (3) Class E (motorway) beam, and (4) Class W (wet road) beam. Those draft regulations also specify a bending mode for each of the four beam classes.

In North America, an SAE recommended practice for AFS, SAE J2591, was issued in September 2002. This AFS recommended practice was developed by the SAE Adaptive Front Lighting System Task Force and sponsored by the SAE Road Illumination Devices Standards Committee. This SAE recommended practice applies to motor vehicle forward illumination devices that incorporate adaptive beam pattern capabilities. This document is to be used in conjunction with other forward lighting standards and/or recommended practices that define base beam procedures, requirements, and guidelines, such as SAE J583 (Front Fog Lamps), SAE J852 (Front Cornering Lamps for Use on Motor Vehicles), SAE J1383 (Performance Requirements for Motor Vehicle Headlamps), and TRANS/WP.29/GRE/2002/18 and 19.

The aggressive regulation change activity through the Eureka Project helped make significant progress in the implementation of AFS technologies. However, North American regulations were ahead of European countries in a certain area: the cornering light. Barton (2003) and Boebel and Rosenhahn (2003) summarized the status of regulations for cornering light. The cornering light was originally synchronized with only direction indicators. In the United States, the revision of SAE J852 in 2001 allowed the use of a cornering light independent of the turn signal. The cornering light can be activated by steering angle. The mounting height between 305 mm to 760 mm allows a lamp to be located in the bumper. The light color can be either white or amber.

In Europe, the new ECE regulation has just been introduced in 2004. The regulation allows additional side illumination combined with low or high beams. It is realized as separate lamp and can be activated at speeds less than 40 km/h by direction indicator or steering angle. Since the mounting height of a cornering light is limited between 250 mm and 900 mm, the lamps can be installed in the bumper. However, it must not be mounted higher than the low beam. The light color must be white. Figures 5.22 and 5.23 compare the legal requirements for the cornering light between SAE and ECE.

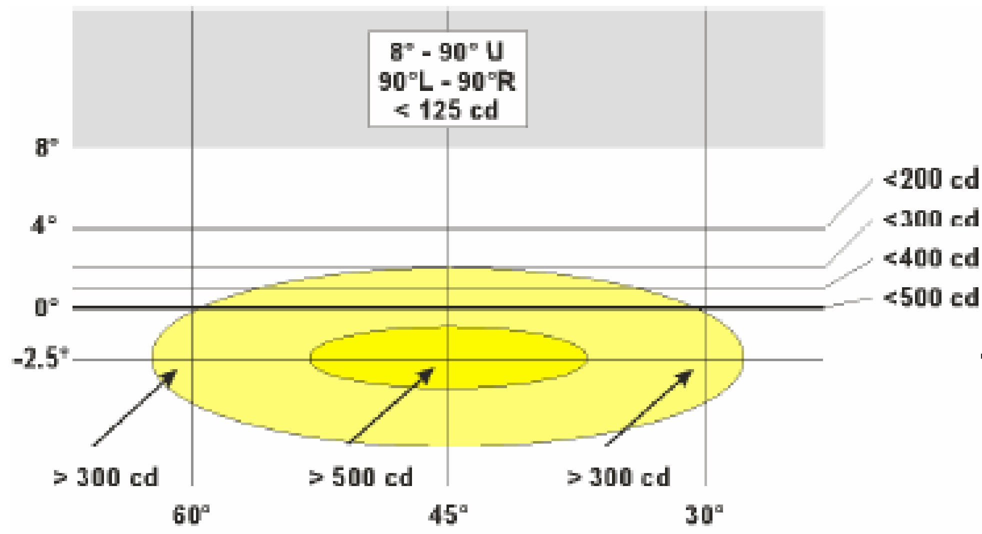


Figure 5.22. SAE cornering light legal requirements (after Boebel, 2003; Barton, 2003).

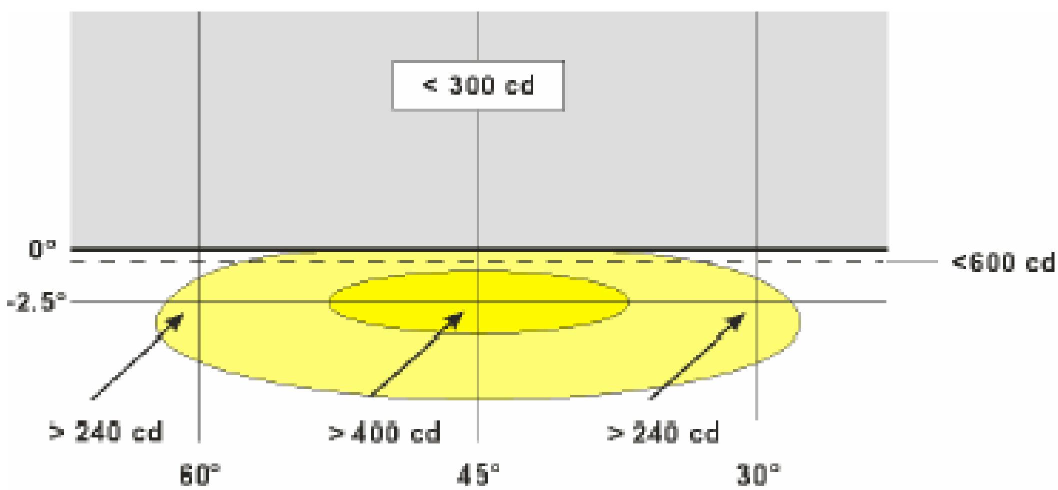


Figure 5.23. ECE cornering light legal requirements (after Boebel, 2003; Barton, 2003).

Regulations Key References

Barton (2003) addressed cornering light in terms of regulations in the US and Europe.
Static bend lighting is an important feature of adaptive light systems. With the improved side illumination it affords obvious advantages to driving situations in intersections, towns and curves. However, these lamps should comply with the ECE and SAE standards. This study concluded that it was possible to have at least one appropriate AFS beam pattern that fulfills all regulations for ECE/SAE cornering light and ECE bend lighting.

- Methodology: iso-illuminance contours
- Type: cornering light
- Scenario: turning corners, lane changing, and parking

Boebel and Rosenhahn (2003) discussed cornering light. Pending legal requirements will allow use of bending beam realized by side illumination from either a part of the low beam or a separate cornering lamp. The first part of this paper compares the legal requirements of both SAE and ECE regulations for bend lighting and cornering light. The second part discusses the performance of different lamps developed on the basis of these regulations. They are compared with respect to technical performance aspects.

- Methodology: iso-illuminance contours
- Type: corning light
- Scenario: turning corners, lane changing, and parking

Regulations Further Information

Economic Commission for Europe Inland Transport Committee, World Forum for Harmonization of Vehicle Regulations (WP.29), Working Party on Lighting and Light-Signaling (GRE) (2004) *GRE-AFS Working Paper No. 6-03--Proposal for a New Draft Regulation: Uniform Provisions Concerning the Approval of Adaptive Frontlighting Systems (AFS) for Motor Vehicles.*

Society of Automobile Engineers, Inc. (2002) *SAE Surface vehicle recommended practice J2591--Adaptive Forward Lighting System.*

5.3.7 Technology

Recent advances in technology allow the AFS concepts to be implemented. These technologies include actuators, sensors, communication systems, laser scanners, radars, gyrators, acceleration sensors, and so on. This survey selected several typical studies on those technologies. This section reviews and summarizes five articles: Elsler (2003), Stam (2001), Roslak (2003), Klein et al. (2003), and Wordenweber et al. (1998). The reviewed articles and their methodologies are summarized in Table 5.7.

Table 5.7. Technology summary.
Beam type: E = Europe; J = Japan; NA = North America.

Beam	Study	Technology	Components	Application
E	Elsler (2003)	actuators	actuators	headlamp leveling, dynamic bending light, VarioX
E	Klein et al. (2003)	bending light	gyrator, accelarator sensors, algorithms (swiveling angle calculation, vehicle speed, curve radius)	aftermarket dynamic, static bending light solutions
E	Roslak (2003)	sensors, communications	radar, LIDAR, laser scanner, video sensor, algorithms (traffic recognition, light adaptation, light pattern production)	technoogy review
NA	Stam (2001)	image-processing and control system	camera, processor, three light sensors, electro-chromic auto-dimming rearview mirror	high beam switching
E	Wordenweber et al. (1998)	vision system	radar, laser scanner, LIDAR, video camera, algorithm (control of headlamp distribution)	various fog densities

Technology main findings

To allow forward lighting to adapt to roadway conditions, it is important to investigate what sensors, optics, and internal information network systems should be used to meet with human factor requirements. It is probably most important to consider what and how information is collected and how the information is used to identify the situation, so that the AFS can optimize the forward lighting distribution. To achieve optimal forward lighting, the flow of information is key.

Figure 5.24 illustrates typical AFS function structure. First, to recognize the traffic situation, it is necessary for the central controller to collect information on the status of the vehicle (position, orientation, and dynamics) and surroundings (road type, weather, and traffic flow). Second, based on the collected information, the AFS will determine an appropriate forward lighting distribution to optimize forward lighting. To achieve the identified light distribution, finally, the controller will send signals to turn on/off each lamp or dim its output. The controller may also swivel the lamp by manipulating actuators.

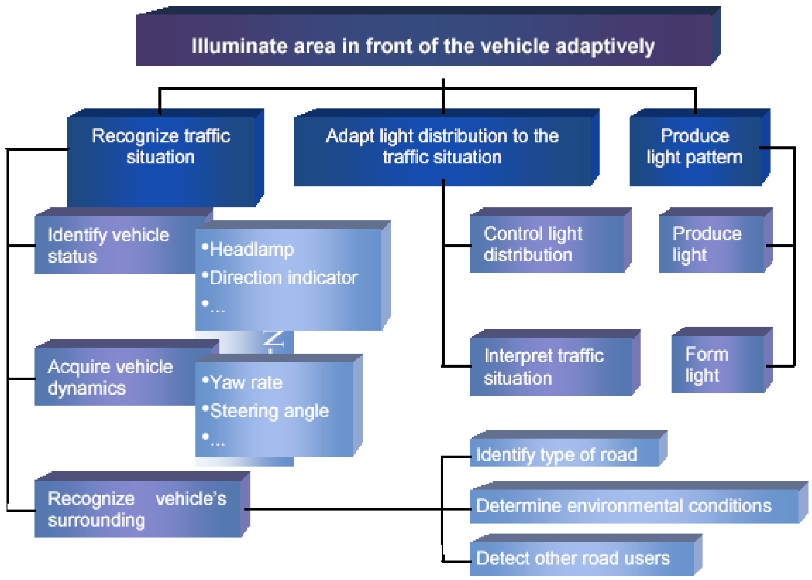


Figure 5.24. Function structure (after Roslak, 2003).

With regard to actuators, Elsler (2003) summarized the current technology of actuators used in headlamps and discussed future improvements in actuators. The author stated that actuators can be improved by reducing; time-lag of referring to sensors, noise, and wiring complexity.

On sensors, Roslak (2003) discussed potential high-tech sensors for AFS including radar, infrared, laser scanner, and artificial vision. Wordenweber (1998) and Stam (2001) also described a new device similar to artificial vision, which may overcome limitations of conventional technology through the use of an image processing system which detects other traffic and switches the high beam accordingly.

Technology Key References

Technology Further Information

Elsler (2003) summarizes the current actuators in headlamps and discusses the future small actuators.

- Technology: Actuators
  Components: Actuators
  Current Actuators: Headlamp Leveling, Dynamic Bending beam, VarioX

Klein et al. (2003) demonstrated combination of gyrator and acceleration sensor, which can be used to generate useable input signals for dynamic and static bending beams. For aftermarket solutions of dynamic or static bending beams, this study found a good opportunity to use alternative sensors, which do not rely on the vehicle electrical architecture and thereby reduce the cost and feasibility of such a solution.

- Technology: Bending beam
- Components
  - Sensors: gyrator, acceleration sensor
  - Algorithms: swiveling angle calculation, vehicle speed and curve radius calculation

Roslak (2003) described various sensors and communication principles of the system for adaptive illumination.

- Technology: sensors and communication systems.
- Components:
  - Sensors: radar, LIDAR (light detection and ranging), laser scanner, and video sensors
  - Algorithms: recognize traffic situation, adapt light distribution to the traffic situation, Produce light pattern

Stam (2001) described a new device, which overcomes limitations of conventional technology through the use of an image processing system which detects other traffic and switches the high beam accordingly.

- Technology: automatic high-beam control system
- Components: a camera, a processor, three light sensors, an electro-chromic auto-dimming rearview mirror.

Wordenweber et al. (1998) described details of the study of visual performance, defines the resolution conditions for existing active safety device and show first examples of vision system applications in automotive headlamps.

- Technology: vision system
- Components
  - Sensors: Radar, Laser scanner, LIDAR (light detection and ranging), Video camera
  - Algorithms: Control of headlamp light distribution

5.3.8 Other applicable AFS research areas

This section describes other headlamp visibility research areas that would inform AFS development and characterization. Publications of research in these areas have not been found specifically relating to AFS. However, examination of these issues would have direct impact on AFS evaluation.

Transition:

When moving from a bright area to a darker area, human vision needs an adaptation time to increase its sensitivity to dimmed light. During this dark adaptation period, the ability of the eyes to detect targets is reduced[3]. Therefore, a large change in headlamp intensity through AFS may impair drivers' forward visibility under certain conditions. This implies that it is important to avoid a large drop in illuminance when switching AFS functions. For instance, when a driver enters a highway from a bright street, the illuminance is suddenly reduced. If the headlamp mode is quickly switched to a narrower motorway beam, the driver may lose his/her peripheral vision for a while because the peripheral area is not sufficiently illuminated by the headlamps. To prevent such a problem, it is important to carefully determine algorithms for transition periods.

Questions to be addressed are:

1) How does a change in adaptation luminance caused by the transition of AFS functions (e.g., from a bending beam to a motorway beam) affect forward visibility?
2) How slowly should a beam pattern transfer from one AFS beam to another to smoothly shift the adaptation level?

Spectral power distribution (SPD):

The current photometry utilizes the CIE 1924 photopic luminous efficiency function,[4] whose peak sensitivity is located at a wavelength of 555 nm. Although the current photometry system was developed for photopic light levels such as those in lit interiors, it is practically used at mesopic light levels as well. For instance, while driving at night, human vision adapts to mesopic light levels. At a mesopic light level, the peak spectral sensitivity of human vision is shifted toward a shorter wavelength (507 nm). Therefore, the current photometry system underestimates the efficacy of a lamp with more short-wavelength components. For instance, an HID headlamp, which usually has more short-wavelength components than halogen headlamps, could be estimated as a lower efficacy lamp; although, under the illumination of an HID lamp, a driver's forward visibility is better than that under halogen headlamp illumination. Recent LRC studies have proved the benefits of HID headlamps under mesopic conditions.[5] To improve the applicability of the current photometry, the LRC proposed a unified photometry system that can cover both mesopic and photopic light levels.[6] The LRC is currently working on the

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[3] Arden, G.B. and Weale, R.A., 1954. Nervous mechanisms and dark adaptation, *Journal of Physiology*, 125, 417-426.

[4] Commission Internationale de l'Eclairage (CIE), 1983. *The basis of physical photometry*, CIE Publication 18.2, Vienna: CIE.

[5] Van Derlofske, J., Bullough, D., 2003. spectral effects of high-intensity discharge automotive forward lighting on visual performance, *SAE SP-1787, Lighting Technology,* 83-90.
Van Derlofske, J., Dyer, D., Bullough, J., Visual benefits of blue coated lamps for automotive forward lighting, *SAE SP-1787, Lighting Technology,* 117-124

[6] Rea, M.S., Bullough, J.D., Freyssinier-Nova, J.P., Bierman, A, A proposed unified system of photometry, *Lighting Research and Technology*, 36, 2, 85-111.

standardization of the unified photometry system. In the meantime, it is also important to understand the difference in spectral sensitivity under different light levels and take advantage of this feature of human vision. For instance, it is technically possible to use a different spectral power distribution for peripheral vision through AFS. While turning a corner, the peripheral vision may be more important to detect potential hazards, such as pedestrians walking along sidewalks and animals about to jump into the roadway. For such a cornering beam, lamps with more short-wavelength components may be more useful. This idea will reinforce drivers' forward visibility through AFS.

Therefore, a question to be addressed is what headlamp SPD and distribution are appropriate for foveal and peripheral target detection and glare?

Section 6: Research Needs

This review found conflicts in evaluation of AFS performance among existing studies. However, it is difficult to identify the cause of such conflicts, since metrics, test scenarios, and evaluation methods used in these studies are often different from each other. For example, one study of glare from bending beams (McLaughlin et al., 2003) shows less glare with bending beams than standard beams on left hand curves in most scenarios, while another study indicates increased glare for a similar situations (Sivak et al., 2001). However, since the former study used the de Boer rating while the latter study used glare illuminance at the eyes, it is difficult to directly compare both data and identify what caused such a conflict between the two experiments. Therefore, it is important to establish common metrics, scenarios and evaluation methods that will allow for consistent evaluation of the effects of AFS on drivers' performance and safety. Based on this finding, the LRC proposes two tasks, to be performed in parallel: (1) identify appropriate metrics for AFS; and (2) develop an AFS prototype.

6.1 Identify metrics for AFS

6.1.1 Identify metrics

To consistently evaluate the effects of AFS on drivers' performance and traffic safety, it is first important to identify common metrics, criteria, scenes, test protocols, and procedures for drivers' forward visibility, glare, and satisfaction.

Forward visibility

To identify a common metric for forward visibility, the LRC would suggest taking an approach of luminance contrast threshold in conjunction with stopping distance.

With regard to forward visibility, the majority of reviewed studies utilized illuminance levels on the roadway. An assumption behind this simple metric is that the higher the illuminance, the better the visibility and therefore safety. This is true if the headlamp can uniformly illuminate the driver's visual field. However, practically, this is not the case. Due to the limitation of luminous flux from headlamps and the need to reduce glare to oncoming drivers, automobile headlamps have to control their output in some areas while maintaining satisfactory forward visibility in others. A bending beam has the potential to achieve this requirement by moving its optical axis to illuminate only where it is needed.

To optimize the bending beam function for driver visibility, it is important to understand where a bending beam should illuminate, particularly examining such factors as pedestrian detection. However, the questions can be asked, what criteria should be used to determine acceptable light levels produced by bending beams in a given area? In order to answer this question, the concept of stopping distance may be useful. This approach considers where and when a driver detects a potential hazard, such as a pedestrian or an animal, and the driver's ability to stop the car and avoid a collision. Once the critical timing and location for the driver to detect the potential hazard are identified (based on possible stopping distance), the second question is how much illuminance is needed for the driver to detect the hazard. To answer this question, luminance contrast threshold data are useful. Many studies addressed the question of what luminance contrast is needed for a target to be detected in conjunction with the target size and the adaptation luminance.[7] The above described approach would also work for a town beam and a motorway beam.

Glare
It is well known there are two types of glare, disability glare and discomfort glare. For discomfort glare, as this literature survey found, many studies utilized glare illuminance at a driver's eyes, as a glare index. An assumption is that glare illuminance corresponds to glare sensation. However, it is not yet clear if glare illuminance determines the degree of discomfort glare. Therefore, it is necessary to examine the relationship by surveying fundamental studies and performing field studies, particularly for glare sources that may rapidly increase their intensity, e.g., at an S curve a headlamp's cutoff may sweep across oncoming drivers' eyes. In the meanwhile, it is also important to attempt to apply an existing glare equation established by Schmidt-Clausen.[8] This glare equation is one that obtains a de Boer rating from various factors, including the luminance of a glare source, the background luminance, and the size of a target. The glare acceptance threshold "4" in the de Boer scale can be the criterion of discomfort glare.

The effect of disability glare on human vision has been investigated for over 60 years and was defined by the equivalent veiling luminance.[9] Since there is a consensus with veiling luminance in the lighting industry, it is appropriate to utilize this method for evaluating AFS.

A third consequence of glare should be considered, and that is glare recovery. Glare recovery is the time it takes for a driver's visual performance to return to its original state after a glare exposure. Studies have shown that glare recovery is proportional to the total glare or glare "dosage" that drivers receive during the time they are exposed to glare. Therefore, the glare dosage produced by AFS should be considered as an important metric.[10]

Higher order perception
Beyond forward visibility and glare, it is important to determine the effect of lighting on higher order perceptions such as satisfaction, preference, and fatigue. To examine such higher order perceptions, the use of subjective evaluations is the simplest method, particularly for short term exposures. For example, is possible to standardize subjective evaluations of discomfort glare by using a specific rating scale, like the de Boer scale.

However, to more objectively evaluate satisfaction, preference, and fatigue, physiological responses can be used. These physiological responses have included brain potential (or

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[7] Blackwell, O.M., Blackwell, H.R., 1971. Visual performance data for 156 normal observers of various ages, Journal of Illuminating Engineering Society, 1, 3-13.
[8] Schmidt-Clausen, H.J., Bindels, J.H., 1974. Assessment of discomfort glare in motor vehicle lighting, Lighting Research and Technology, 6, 79-88.
[9] Stiles and Crawford, 1937
[10] Chen, J., 2004. Effects of headlamp glare exposure on glare recovery and discomfort, Master of Science in Lighting, Lighting Research Center, Rensselaer Polytechnic Institute: Troy NY.
Irikura, T., 1999. Recovery time of visual acuity after exposure to a glare source, *Lighting Research and Technology*, 31, 2, 57-61.

electroencepharogram), electrocardiogram, and electrodermal activity.[11] The brain potential reflects the activity of the central nervous system and can be used as an index of arousal level. When a subject's arousal level is reduced due to drowsiness or fatigue, the brain potential tends to contain lower frequency components such as so-called alpha waves. The electrocardiogram and electrodermal activity reflects the activity of the autonomic nerve system that is related to the status of emotion, stress, and fatigue. Therefore, it is possible to objectively evaluate the mental loads of driving tasks under different lighting conditions and therefore indirectly evaluate higher order perceptions.

6.1.2 Calculate evaluation of AFS functions

Once the metrics and criteria are identified, one can use analytical techniques to consistently evaluate AFS functionality. Standardized performance criteria will allow for calculating and comparing forward visibility and glare between different headlamp beam patterns for different scenarios. This process will help to preliminarily identify appropriate headlamp luminous intensity distributions and operational algorithms for each AFS function.

6.1.3 Tie the metrics and criteria to driver behavior

To verify the validity of the developed metrics and criteria and to better understand the correlation of those criteria with traffic safety, they should be compared to the results of research efforts such as the 100-car naturalistic study.

6.2 Develop an AFS prototype

6.2.1 AFS prototype development

The first task, "Identify AFS metrics," will identify a potential range of headlamp luminous intensities and distributions. This identified range will help specify the requirements of an AFS prototype. The prototype will be composed of headlamps, actuators, sensors, and control systems. The headlamps will consist of multiple and/or replaceable lamps and adjustable optics, so that the luminous intensity distribution and perhaps the spectral power distribution of the lamps can be varied easily. The actuators will have the ability to cover different movement algorithms, such as one-lamp swiveling, two-lamp symmetrical swiveling, and two-lamp asymmetrical swiveling. For a certain sensing function, this prototype will allow for testing of multiple sensors by electrically switching the wiring. The control system will be computerized and make it possible to manipulate the headlamps by various operation algorithms, which are stored in the computer's memory. It is eventually most important that this prototype be mountable to any vehicle. This will allow test drivers to drive enclosed test tracks and public roadways.

The LRC will make the best use of its industry contacts to examine existing AFS technologies, especially to seek appropriate sensors to dim headlamps or change beam patterns selectively. In this whole process, the LRC will collaborate with NHTSA on the prototype development.

The creation of a prototype AFS system will not only allow for the design and performance of field studies to directly evaluate AFS effectiveness, but will provide information on the capabilities and limits of AFS due to its inherent technology and design.

[11] Hugdahl, Kenneth, 1998. *Psychophysiology: the mind-body perspective.* Cambridge, Massachusetts: Harvard University Press.

6.2.2 Field study

To evaluate the effects of AFS functionality on forward visibility, glare, and traffic safety, the final stage of this proposed study will be to conduct field studies by using the developed prototype. These field studies will prioritize the evaluations of bending beam and town beam functionality. For the bending beam evaluation, this prototype will be able to individually control the luminous intensity distribution, the source spectral distribution, and the swiveling algorithm. To optimize the AFS functionality, the field studies will attempt to answer the following questions:

For bending beams:

Can a bending beam provide better forward visibility, reduce glare to oncoming drivers, and increase traffic safety?

Which performs best in terms of target visibility and glare reduction among three typical dynamics: a one-lamp swivel, a two-lamp swivel with the same bending angle, or a two-lamp swivel with different bending angles?

How early should a headlamp start to swivel before reaching a curve and how fast should the headlamp orientation complete its change?

What spectral power distributions of headlamps should be used to increase peripheral visibility?

For town beams:

Can dimming forward headlamps minimize glare to oncoming vehicles without impairing driver visibility?

Can selective dimming be done only in the direction of an oncoming vehicle?

How much can the intensity of headlamp beams be reduced to minimize glare to oncoming drivers, pedestrians, and household residents while maintaining visibility and comfort?

How bright should ambient roadway illuminance be to reduce headlamp intensity?

How bright should the headlamp beams remain to effectively signal to other drivers and pedestrians?

As other functions, motorway beams and adverse weather beams will be potentially discussed:

Can a motorway beam improve forward visibility, reduce glare, and increase traffic safety?

How can motorway beams be achieved? How wide and far should the beam illuminate as a function of speed?

How can an adverse weather beam improve forward visibility or traffic safety?

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Appendix A: Relevant Literature

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Appendix B: Reviewed Literature

Adler, B. and Lunenfeld, H. (1974). ***Evaluation of a three-beam vehicle lighting system.*** **Transportation Research Record #502, p.22-33. (NA)**

This paper introduces the concept of a middle range beam for use between low and high beam modes. A 3-beam 4-headlamp system is evaluated in three phases: a low-mid-high beam using 2-3-2 headlamps respectively, a 2-3-3 configuration, and a 2-3-4 configuration. The three beam configurations are described in the paper. Following glare, oncoming glare, and seeing distance were evaluated. A computer program was used to calculate following glare and showed "very minor differences" from conventional headlamp systems; actually the 2-3-3 and 2-3-4 designs both produced higher amounts of following glare than the 2-3-2. For oncoming glare, however, the 2-3-4 system prompted the fewest number of dimming requests, followed by the 2-3-3 and then the 2-3-2 systems. Seeing distance was consistently improved with the 2-3-4 configuration: with oncoming glare (24ft lateral separation), seeing distance was greatest with the 2-3-4 setup; with oncoming glare (12ft lateral separation), seeing distance was best using low beams, second best using mid-beams, and of the high beam configurations 2-3-4 worked best; with no oncoming glare, mid-beam and 2-3-4 high beam both provided the greatest seeing distance.

Akashi, Y., Dee, P., Chen, J., Van Derlofske, J., Bullough, J. (2003). ***Interaction between fixed roadway lighting and vehicle forward lighting*****. PAL 2003 vol. 10, p.11-22. (NA)**

A field study was conducted to investigate how vehicle headlamps contribute to target detection in lit areas and therefore how headlamps interact with fixed roadway lighting. This study measured recognition distance of targets on a paved roadway under different fixed roadway lighting illuminance and headlamp intensity conditions. Five targets moved on straight lines that radiated from a stationary car in five directions, -15°, -5°, 0°, 5°, and 15°. Each of eight subjects sat in the car, fixated on a signboard at a distance of 100m, and signaled target detection by releasing a manual switch. The results of the study showed a consistent tendency that recognition distance of targets increased as roadway illuminance increased. However, headlamps little improved target visibility as headlamp intensity increased. The results implied that, to reduce the impact of headlamp glare on oncoming drivers, the headlamp intensity could be dimmed without impairing target visibility in lit areas. The final paper may present more subject data, ambient illuminance conditions under which headlamp intensity can be dimmed, and how low headlamp intensity can be while maintaining drivers' visual performance under various ambient illuminance conditions.

Barton, S. (2003). ***Cornering Lamp and Static Bend Lighting - Harmonized Technical Realization in ECE and US.*** **PAL 2003 vol. 10, p.92-103. (E)**

Static bend lighting is an important feature of adaptive light systems. With improved side illumination, it affords obvious advantages to driving situations in intersections, towns and curves. However, these lamps should comply with the ECE and SAE standards. This study concluded that it was possible to have at least one appropriate AFS beam pattern that fulfills all regulations for ECE/SAE cornering lights and ECE bend lighting.

Birch, S. (2001). ***Adaptive front lighting*****. Automotive Engineering vol. 109 no.12 p.39-42. (E)**

Vehicle lighting development has been a relatively slow process, with better lighting performance often being achieved by having bigger headlights or more of them. This article discusses a project with an aim to enhance the lighting performance through a clearer definition of the cutoff in terms of sharpness and geometry of the light, reduction of the

illuminance in the area in front of the vehicle, and a reduction of self-glare. The partners in the program for the development of a 'Variable Intelligent Lighting System' (VARILIS) include numerous automobile manufacturers and lighting system specialists. Some of the specific issues VARILIS is addressing include: direct lighting of the area immediately in front of the car under different weather conditions; the long-range, narrow pattern of light distribution that is ideal for high-speed travel on motorways but unsuitable on twisting country roads; safety issues including headlamp illumination in low light conditions and the ability to differentiate between high natural ambient light levels and high artificial levels. The program addressed direct lighting of the area immediately in front of the car, which is desirable when the road surface is dry but can create glare for oncoming traffic when wet, while light emitted above the cutoff line in fog can create glare for the driver.

Hella defines five principal conditions as follows:

(1) Town light: Areas of high intensity within the light distribution are unnecessary.

(2) Country light: demands include recognition of the course of the road and objects in the vicinity of the road; guidance of the driver's attention to relevant areas of the road; and low levels of glare to other road users. A curved cutoff provides this.

(3) Motorway type light: A symmetrical beam pattern with a sharp cutoff and very small forward rake angle is the best approach. High levels of illuminance (80-100 lx) must be generated directly at the cutoff. Glare to oncoming traffic is prevented by stable vehicle dynamics and a fast, dynamic headlamp leveling system.

(4) Adverse weather light: Reflection on the wet road causes glare to oncoming drivers. Because of the high proportion of light reflected forward, the driver becomes aware of a reduction in illuminance in front of his or her vehicle. So, the level of illumination in the immediate frontal zone—up to about 20m in front of the vehicle— should be reduced to an acceptable level to oncoming traffic.

(5) Bending beam: For both static and dynamic bending beam, cutoff prevents glare to oncoming traffic.

Boebel, D., Rosenhahn, E. (2003). ***Cornering lamps and static bend lighting– performance aspects and technical comparison in AFS-Systems*****. SAE technical paper #2003-01-0554. (E)**

This paper discusses the foundations for headlamp system components and performance parameters. One of the most important features of a headlamp with adaptive light distribution is the improved side illumination for driving situations in towns, at intersections and in small radius curves. Pending legal requirements will allow use of bending beam realized by side illumination from either a part of the low beam or a separate cornering lamp. The first part of this paper compares the legal requirements of both SAE and ECE regulations for bend lighting and cornering lamps. The second part discusses the performance of different lamps developed on the basis of these regulations. They are compared with respect to technical performance aspects. Key findings include

1: dirt can increase glare to oncoming drivers (in the glare zone 0^o to 2^o above horizontal) by a factor of 4 to 7 while reducing illumination below the cutoff line.

2: vertical aim is more critical than horizontal aim; 1^o of horizontal misaim reduces headlamp range to 85% of correct aim, while 1^o of vertical misaim reduces headlamp range to 46%. Vertical aim is extremely sensitive to any kind of load, passengers or trunk.

3: power supply variations have an exponential effect on halogen lamp lifetime but a minimal effect on range of light output.

Boehlau, C. (2001). ***Optical Sensors for AFS – Supplement and Alternative to GPS*. PAL 2001 vol. 8. (E)**

AFS will be introduced into the market in two steps: cornering or bending beam (BL), and Motorway Light (ML)/ Country Light (CL)/ Town Light (TL). Sensors are necessary for a more extended light assistance system, whose task it will be to recognize the current traffic and environmental situation. For the ML/CL/TL system, it is suggested that an artificial image processing system can be used combined with a cheap "townlight-sensor"; artificial illumination ranges from 0.1 to 10 lx. For adverse weather lights, current rain sensors are not adequate; a visibility sensor, such as a camera-based imaging system or infrared sensor, is required. Fog, spray, droplets, and aerosols appear as a fuzzy target directly in front of the car, where backscatter is greatest.

Chowdhary, M. (2002). ***Driver assistance applications based on automotive navigation system infrastructure.* International Conference on Consumer Electronics 2002: Digest of technical papers, p.38-39. (NA)**

This paper describes an adaptive front-lighting system (AFS) and a curve speed warning system (CSWS) as they relate to the architecture of an automobile navigation system.

Damasky, J. and Huhn, W. (1997). ***Variable Headlamp Beam Pattern – Lighting Requirements for Different Driving Situations*. SAE technical paper #970647. (E)**

This paper introduces different beam patterns, and their necessity based on road geometry analysis using videotapes and computer simulation. Driving situations are divided into four categories: urban road, small country road, large country road, and motorways. The statistical probability of pedestrians and signs at specific locations are assessed for each type, and a beam pattern is developed to provide minimum illumination at these locations:

Urban beam pattern: the aerial view isolux diagram has a wide distribution, with no sharp cutoff.

Country road: side illumination is emphasized and glare is a bigger problem here, so a heart-shaped beam pattern with a cutoff is suggested. Swiveling headlights are needed for narrow country road curves (threshold curve radius 2500m).

Motorway: long throw, narrow distribution with a sharp cutoff to minimize oncoming and rearview mirror glare while maximizing straightaway visibility.

Adverse weather lighting: beam pattern developed to minimize oncoming glare from altered reflectivity coefficients of wet roads and self-glare from fog, with a low and uniform light level above horizontal and emphasized illuminance at the side lane markers for guidance.

Dassanayake, M., et al. (1999) ***Remote HID headlamp systems*. SAE technical paper #1999-01-0386. (NA)**

Significant interest in high intensity discharge headlamps (HID) has developed in the past few years. They have evolved as a safety device in the high-end luxury automobile segments, and are now showing demand for applications in other vehicle lines as well. However, affordability of these systems has been a continuous problem for all vehicle lines. A headlamp system that consists of: a remotely located light collector integrated to an HID source and ballast, a pair of light cables and distribution optics at the output of the light cables is being presented as a low cost alternative to HID headlamps. It also offers significant reductions in vehicle power consumption and radically new styling options. Five different concepts for light distribution optics are discussed along with their performance compared to conventional HID and halogen headlamps.

Diem, C. et al. (1999). ***Analysis of eye movement behavior using movable headlamps*****. PAL vol.5, p.185-207. (E)**
A study conducted to measure fixation behavior of drivers at night and day, using halogen and gas discharge lamps [GDL], static and moveable [5 test conditions total], on an empty 8km test track. Movable headlamps result in more distant fixation points than static, for both halogen and GDL; movable halogen headlamps do not produce fixation points as distant as static GDL. In the case of static halogen headlamps, two fixation points are produced in curves— drivers scan the road for lane keeping.

Diem, C. (2003). ***Different control parameters of the bending beam function-influence on the driver*****. PAL 2003 vol. 10, p.231-241. (E)**
A study conducted to compare driver's subjective rating with eye fixation distance for different movable headlamp configurations. A test car was equipped with horizontally movable HID headlights (+/- 20^{o}) and an eye-tracking system. A test track was used with curve radii of 43m and 293m. The calculation algorithm for the angle of the curve-inside headlamp remained constant while the relative angle between the headlamps was varied from 0%, 50%, 100%, and 150%. For a 293m radius curve and standard (immobile) headlamps, fixation distance is 34m in front of the car. 0% (only inside headlamp bends) fixation distance is 40m. The 100% setting optimizes fixation distance at 60m, and 50% and 150% are comparable. Subjective ratings: ratings for one movable headlamp (0%) are the same as for standard (immobile) and the middle of the road looks dark so detection will be poor; 100% gets the best brightness rating and provides improved information about the road course.

Frieding, A. (1999). ***Optimized headlamps for wet road conditions*****. PAL 1999 vol.5, p.307-315. (E)**
Rain increases forward and reduces backward reflection, decreasing adaptation luminance, contrast sensitivity, increasing glare sensitivity and reducing overall visual efficiency. Maximum road luminance for the driver from dry to wet is calculated to decrease by two orders of magnitude. In wet conditions, reduced luminance (25% and 50% of dry) in the central roadway zone is deemed "acceptable", purportedly due to decreased adaptation luminance, but greater emphasis is placed on side land markers for orientation, so desired luminance is increased to 180% on the left and 220% on the right. Evaluations took place on 80km of country road, federal highway, and motorway.

Grimm, M. (2001). ***Improved nighttime visibility for drivers through dynamic bend lighting*****. PAL 2001 vol. 8, p.339-347. (E)**
Recognition distance for certain objects decreases for dynamic driving. Modern sensors and actuators allow compensation for the influence of the dynamics in order to keep recognition distance and glare controlled. Both driver and oncoming car gain from a bend lighting system.

Hamm, M. (2001). ***System Strategies for Adaptive Lighting Systems*****. PAL 2001 vol. 8, p.368-380. (E)**
This is a review article on the development of AFS concept and market foundation. Several ways to modify beam pattern: additional modules that can switch on and off (easy but space-wasting), movable parts (more sophisticated), and power control of HIDs. Algorithm for control system hierarchy is presented. As compared with halogen, AFS increases seeing distance in curves, motorways, and turns by 168%, 211%, and 246% respectively, and HID increases these seeing distances by 123%, 122%, and 131%.

Hamm, M. and Rosenhahn, E-O. (2001). ***System strategies and technology for improved safety and comfort with adaptive headlamps*****. SAE technical paper #2001-01-0299. (E)**
Photometric measurements to rate glare effects during curve road driving for different AFS headlamp algorithms are carried out. All tests used HID headlamps. By using an experimental headlamp prototype with freely programmable parameters, three different systems were tested: a conventional headlamp system, a video sensor information (predicting) algorithm system, and a steering wheel angle information algorithm system. Target detection distances were measured for a small gray target on the righthand side of the road for a car driver who drives a left hand curve (or a right hand curve). At curve entrance, the predicting system increased detection distance by 35% of conventional; during curve driving, both predicting and steering systems improve detection distance ~29%; at curve end, both predicting and steering systems improve detection distance ~35%. Glare illuminance levels for the three headlamp algorithms were measured. For a lefthand curve, glare for both predicting and steering systems are found to be equivalent to conventional at short distances and lower than conventional systems in the range from 60m to 130m. For a righthand (250m radius) all glare illuminances are equal. The conclusion is that it is possible to increase driver visual range without increasing glare for other drivers. The advantages (in road illumination) of the application of AFS lighting in motorway, turns, and intersection lighting are discussed.

Hamm, M. (2002). ***Adaptive lighting functions history and future-- performance investigations and field test for user's acceptance*****. SAE technical paper #2002-01-0526. (E)**
Adaptive lighting systems approach the market by showing additional value to the customer. Different possibilities are discussed like additional modules that are switched on, light sources with power controlled luminous output ("dimming") or modules which are enable to swivel parts of the light distribution or swiveling the full light distribution itself. The result can be measured in photometric parameters as luminous flux candelas or lux or as well in geometrical parameters as range, sidespread, covered area etc. This paper adds another aspect to the usual photometric discussion of the new technologies: the way a standard driver experiences and accepts the new and rather unused technology of adaptive lighting system. Subjective ratings from drivers show that 45% of all drivers believe curve lighting is the most important function for lighting, with turning and motorway lighting running a close second. 35% believe the turning light is the most important function for safety, and 33% believe the motorway light is most important for comfort. The town light only collected 2% to 4% of the votes in any category (safety feeling, comfort, peculiarity, and "driving fun").

Hamm, M. and Rosenhahn, E-O. (2003). ***Facts and feelings regarding motorway light in adaptive headlamp systems*****. SAE technical paper #2003-01-0552. (E)**
AFS generate different lighting patterns according to the environmental situation that is evaluated by electronic control units. This paper focuses on the motorway function, fields of interest, traffic safety, and comfort acceptance results. The photometric performance of the motorway function is shown in measurement and in comparison to the existing driving situations with standard headlamps. The improvements of an AFS motorway function are discussed in visibility/detection distance, reaction distances and braking distance calculations. Much of the data from the user survey/questionnaire that is presented in this paper is the same as that in reference (14).

Hamm, M. (2003). ***US, Japan, and European market investigation on applied technology and styling trends in domestic and imported cars*****. PAL 2003 vol. 10, p.356-364. (E)**

Styling and technical functionality rule the headlamp market. HID and xenon-bifunction headlamps have infiltrated and overtaken the market since 1999. Projection-type, movable shutter systems currently dominate the European market at 82%, and is only at 17% in Japan, indicating a clear styling trend separation between Europe and Japan with a complex, style-based root cause. Reflection technology takes 54% of the market worldwide.

Hamm, M. (2004). ***HID headlamp development: performance benchmark, market penetration and future styling development in world's markets*****. SAE technical paper #2004-01-1283. (E)**

This paper describes basic HID headlamp system functionality, performance improvements from 1995 to 2003, world market penetration of HID technology, and consequential styling effects. The market data is the same as that used in the previous reference (Hamm PAL 2003). Over the past decade the light distribution of HID systems has changed. In terms of hardware, the average projection system lens diameter has increased by ~10mm and exit area has increased slightly, whereas the average reflection system reflector size has decreased, and exit area has decreased drastically. In general projection systems use ~20-25% of the exit area that reflection systems use. Conclusions are that projection systems are superior to reflection systems in sidespread, luminous flux, and geometric requirements, and that there is no clear cause for the difference in dominance of styling trends in the big three world markets (US, Japan/Asia, and Europe).

Hara, T. Kuramochi,T., Ayama, M., Kojima, S. and Sato, K. (2001). ***Evaluation of AFS from driver's point of view*****. PAL 2001 vol.8, p.397-402. (J)**

In this study, newly developed AFS was evaluated using video image data taken from the position close to the driver's view with driver's eye marks during on-road nighttime driving. Subjective estimation of the participant drivers indicated higher marks for AFS-ON than AFS-OFF.

Hogrefe, H. and Neumann, R. (1997). ***Adaptive Light Pattern – A New Way to Improve Light Quality.*** **SAE technical paper #970644. (E)**

Review article of AFS concepts. Town, country, motorway beam patterns are explained. Beam pattern changing technology and controls are reviewed. A distinction is made between direct automatic control and more sophisticated predictive controls.

Hogrefe, Henning. (1999). ***Headlamp Components for Adaptive Frontlighting: CurveLighting & SpotLighting*****. PAL 1999 vol. 5, p.405-411. (E)**

An AFS task-force [EUREKA] has performed test drives with two movable headlamp systems: one type in which the basic reflector is also used for curve light, and one with separate curve reflectors. These systems "give a good impression". Systems with variable internal optics seem to be too delicate to be practical. Sharp bends and crossroads are best illuminated when static curve lighting components are added to movable systems. Good spotlighting is achieved using ellipsoid projection systems and an H7 bulb when well-matched with layout of the basic light pattern.

Hogrefe, H. (2000). ***Adaptive frontlighting systems for optimum illumination of curved roads, highway lanes and other driving situations*****. SAE technical paper #2000-01-0431. (E)**

Three experimental curve lighting systems are developed using static and movable beam components. Long range illumination without glare is achieved using separate spot modules or a raised basic beam cutoff. All systems provided enhanced road illumination at curves.

Ikegaya, M. and Ohkawa, M. (2003). ***Study of distribution control methods for AFS.*** **PAL 2003 vol. 10, p.426-439. (J)**

This study conducted simulations to identify the effects of beam patterns and swiveling operation on driving performance, safety, and effectiveness under different driving situations. The simulation results were compared with a roadway field test. The dependent variables were recognition distance and stopping distance. This paper also suggests requirements for AFS. (This paper does not describe the details of the simulation and evaluation.)

Ishiguro, K. and Yamada, Y. (2004). ***Control technology for bending mode AFS.*** **SAE technical paper #2004-01-0441. (J)**

Eye fixation points are measured and used to design AFS control logic. Main beam maximum swivel angle is calculated to be arcsine (50H/R); for 250m this is ~8^{o}. The experiment was conducted with a right-hand drive sedan in the lefthand lane of a test track with turns from 20m to 250m radius driven at speeds of 30, 45, and 60 km/h. HID headlamps with righthand drive beam patterns were used. 10 subjects used for day, 3 subjects used for night. Night gaze is more fixated on centerline than daytime gaze; fixation point moves further along the curve as speed increases. The swivel angle was designed to optimize visibility of the turn radius by allowing the driver to see a spot on the road t=3seconds into the future to mimic eye fixation points. The test vehicle used in this experiment only swiveled one headlamp at a time, depending on curve.

JARI (2001). ***Japan Automobile Research Institute's report on research commissioned by the Japan Automobile Manufacturers Association-Research on AFS (second year of three year project)*****. (J)**

JARI (2001) evaluated glare through computer simulations, as well as a field test, which determined oncoming drivers' eye position. For the field test (on Japanese roads), the criteria for glare was whether or nor the oncoming drivers' eye position was above (no glare sensation) or below (glare sensation) the headlamp distribution cut-off. Eye positions of the oncoming drivers were determined, at a distance 50m in front of the test vehicle, by using a CCD camera installed on the test vehicle. It is unclear as to what type of swivel system was used and there was no mention of lamp type. 435 miles of public roads were videotaped and analyzed.

For left-hand curves (no mention of radii) the number of drivers recorded was 199. The authors found a smaller percentage of eye-points below the beam cut-off line with the swivel compared to the standard position, concluding that a swivel system will produce less of a glare sensation. For right-hand curves the number of drivers recorded was 174. The authors fail to include percentages as they did with the left-hand curve. However they state that there were no eye-points recorded which fell below the beam cut-off line, and therefore, "no possibility of glare imparted to oncoming vehicles even with swiveling headlamps" (p.10).

For an S-curve the number of drivers recorded was 21. The swivel position illuminating an S-curve consisting of a left-hand curve into right-hand curve did not demonstrate the potential for more glare than with headlamps in a standard position. However a greater potential for glare was demonstrated with the swivel position illuminating an S-curve consisting of a right-hand curve into left-hand curve.

Computer simulations utilized the following assumption: vehicle speeds of 30km/h, 45km/h, and 50km/h for curves with r= 30m, 50m, and 70m respectively; a standard HID system, a one-sided swivel system (ά and 0°), and a parallel swivel system (assume symmetrical). According to the authors, the simulations calculated illuminance at the eye, and these light levels were equated to discomfort glare through the Deveau 9 point scale. For the Deveau scale, below 5 is acceptable. (Note: reversal of scale vs. de Boer scale). According to the authors, a 5 on the Deveau scale is equivalent to a veiling luminance= 0.15 cd/m^2 (note: veiling luminance is a measure usually associated with disability glare). Having said that, no data was presented which gave Deveau ratings; rather illuminance values at the eye were provided.

For the left-hand curve scenario, their results demonstrate that peak illuminance values occurred (for the three types of headlamp systems) at different separation distances between the simulated glare-vehicle, and simulated oncoming vehicle. This did not occur with the right-hand curve scenario (for the three types of headlamp systems, illuminance peaks occurred at the nearest point separating the two vehicles, regardless of curve radius).

For the left-hand curve, the authors present numerous graphs for the various radii indicating illuminance levels at the eye as a function of separation distance. While these data are interesting, little information can be extrapolated from a computer simulation in regards to discomfort glare. There are however some generalizations which the simulations demonstrated. For all three headlamp systems, as well as all three curve radii, illuminance levels for a left-hand curve (in Japan) can exceed the values seen with a right-hand curve, by up to approximately ½ log unit to 1 log unit, depending on the separation distance between vehicles.

Computer simulations also looked at S-curves (left-hand curve into right-hand curve, and right-hand curve into left-hand curve). Similar to the results found for the left-hand curve above, S-curves demonstrated peak illuminance values (for the three types of headlamp systems) at different separation distances between the simulated glare-vehicle, and simulated oncoming vehicle. However there were three exceptions. These exceptions all were at the entry point of the S-curve (right-hand curve into left-hand curve). At the entry point of these types of S-curves (for the three types of headlamp systems) illuminance peaks occurred at the nearest point separating the two vehicles, regardless of curve radius.

The authors also investigated glare imparted to oncoming vehicles by a vehicle waiting to turn right (on Japanese roads). In this scenario, the parallel swivel system clearly produced more illuminance at the eye than the one-sided swivel system and the standard system. The standard system produced the lowest illuminance at the eye.

Jost, K. (2002). ***Bending beam.*** **Automotive Engineering, vol.110 no.12, p.26-31. (NA)**

Lighting technology is becoming more intelligent and adaptive as OEMs and suppliers develop systems that are more integrated into vehicle electronics systems for greater performance and safety. This article reviews recent AFS innovations of major OEM AFS manufacturers and the car models they are being tested in.

Kalze, F. (1999). ***Static bending beam – a new light function for modern headlamp systems.*** **SAE technical paper #1999-01-1212. (E)**

A new light function called static bending beam is described. The target of this function is to add to the well-known dipped beam light distribution in xenon or halogen technology a bending beam function which gives light in areas which normally are not reached by a standard dipped beam. A standard dipped beam light distribution illuminates the traffic room directly in the front of the car up to far distance areas of more than 100 m. The side areas close to the car up to a distance of 20-30m are not illuminated by this distribution. This “no man’s land” could be illuminated by a special light function which is described in this paper.

1: The side area close to a car up to a distance of 20-30m, called “no man’s land” was considered. This area reinforces peripheral vision while turning to the right or left.

2: Computer software, called Light Distribution Editor (LDE) was used for the simulation.

3: This paper mentioned that a cutoff-line to avoid glare to oncoming traffic was also considered but no data were shown for the cutoff-line.

Kalze, J. (2001). *Situation Adapted Light Distributions for AFS Headlamps*. PAL 2001 vol.8. (E)

The global headlamp system of the future isn't only an optical system creating well known lighting functions like: low beam, high beam, and fog beam, but it's an intelligent system where sensory elements detect the situation, an ECU controller defines the algorithmic of reaction and power units drive actuators within the optical system with the target to manipulate the light distribution.

1: Hella's AFS concept was summarized. The headlamp system is composed of a basic light module (left and right headlamp), high beam, and static bending beam and provides a comfortable compromise between visibility distance, reduced glare for oncoming traffic, and comfortable spread of homogeneity.

2: In town light mode, the basic light modules have symmetrical cutoff line geometry. Depending on speed, the modules are swiveled.

3: In night rain situations, the left basic light module generates a horizontal cutoff line and is forced into divergent mode with an angle of 15 degrees. The right module generates the motorway cutoff line with divergent mode of 5 degrees. This beam pattern can reduce reflex glare to the oncoming traffic.

4: It is not reported how the cutoff lines were determined.

Kobayashi, S. and Hayakawa, M. (1991). *Beam controllable headlighting systems*. SAE technical paper #910829. (J)

AFS prototypes were developed using a halogen source. A partial beam control system consisting of a fixed beam and a moving beam, and a total control projector system consisting of a static outer aspheric lens (f1=60mm) and an inside Fresnel lens (f=75mm, movable forward and back +/-20mm, sideways 35mm) were developed. 2 DC motors were used for the movable lens (1 for each axis of movement). Lens position was controlled by vehicle speed and road curvature radius. For both systems, left and right headlights could move independently and the angular separation between them had a linear relationship with vehicle speed. Resulting beam patterns are shown but no user/driver data is included in this paper.

Kobayashi, S., Takahashi, K. and Yagi, S. (1997). *Development of new forward lighting systems with controllable beams.* SAE technical paper #970646. (J)

This study did not evaluate a bending-beam, rather their evaluation compared illumination around a curve (r=140m) using a standard halogen low beam, and an early prototype of an HID low beam. No subjects were used. Illuminance values were taken at 100m from the vehicle with the light source, though no indication of methodology is provided (e.g., height of illuminance detector). De Boer ratings were calculated assuming an adaptation luminance of 1 cd/m^2. Calculated De Boer ratings were above the 'just acceptable' (rating of 4) except for one condition when the HID prototype was elevated such that the cut-off (assume Japanese beam pattern) was raised 1.5 degrees.

Kobayashi, Shoji. (1998). *Intelligent lighting systems: their history, function, and direction of development.* Automotive Engineering, vol.106 no.10, p.19-24.

This article gives an overview of intelligent lighting systems (ILS) that are designed to improve the safety and comfort of nighttime driving. It focuses on a system which controls

headlamp beam patterns according to car speed, steering, weather conditions, and the presence of other vehicles.

Kobayashi, S., Hayami,T., Sugimoto, A. and Uchida, H. (1999). ***Development of the Phase-I AFS front lighting system.*** **PAL 1999 vol.5, p.449-464. (J)**

Multiple beam patterns have been identified to satisfy requirements of various driving scenes (motorway beam, country beam, and town beam) with additional function beams (adverse weather beam, bending beam, overhead sign beam, dipping and dimming beams). Bending beams have been divided into four categories [high-speed, middle-speed, low-speed, and crossroads cornering]. A demonstration vehicle was built with four lamps to provide the four beams: all beams are controlled by speed and steering sensors, and the main beam is movable. Algorithms for beam control and switching are provided. Evaluation by 8 subjects indicates substantial improvement over traditional headlamp systems. Future developments involve the incorporation of additional road information by accessing roadmaps through GPS and collecting weather and road condition data through additional sensors.

Kosmatka, W.J. (2003). ***Differences in Detection of Moving Pedestrians Attributable to Beam Patterns and Speeds.*** **PAL 2003 vol.10, p.549-566. (NA)**

A luminance simulation for dark-clad pedestrians illuminated by US headlamp types shows that differences between lefthand and righthand detection distances (righthand detection distance is better) is attributable to characteristics of the light source. As might be expected, findings are that modern devices with more flux allow longer detection distances; pedestrians are more detectable when crossing from the right than from the left; pedestrians are most detectable on the right, then in the center, then on the left; and detection distances for roadway-crossing pedestrians increase with the ratio of the vehicle's velocity to the pedestrian's velocity.

Lehnert, Peter. (1999). ***CaLIST— A Lighting Tool for Designing Dynamic Headlamp Leveling Systems.*** **PAL 1999 vol.5, p.480-491. (E)**

A dynamic headlamp leveling system is an adaptive light function that compensates for a vehicle's vertical tilt dynamics relative to its own axes to minimize dynamic glare. Demands on a dynamic leveling system are discussed in terms of disability and discomfort for both driver and oncoming driver. A computer aided lighting simulation tool [CaLIST] simplifies evaluation of these systems by not requiring a real prototype.

Leleve, J., Wiegand, B. (2003). ***Multifunction projector.*** **SAE technical paper #2003-01-0553. (E)**

This paper proposes an alternative AFS design solution to reduce glare during transitory phases, consisting of a conical shield holder which rotates along a vertically tilted axis. An optimal light distribution is generated by a precisely defined distance between the lens and shield, and a curved shield shape. The rotating shield is driven by a motor, and positioning is guaranteed with an optical sensor. This multifunction projector is easily installed into standard elliptical projector headlamps. The paper describes the mechanical, electrical, and optical components of the design, as well as accuracy and reliability.

Lowenau, J. et al. (1997). ***Adaptive light control using real-time light simulation for the development of movable headlamps.*** **PAL 1997 vol. 3, p.389-401. (E)**

An adaptive light control [ALC] system installed in a BMW is simulated and compared with static headlamp systems. The paper is really about the software developed for this analysis (which uses 30-60 frames/second), to circumvent construction of expensive prototypes,

Lowenau, J. P. et al. (2000). ***Advanced vehicle navigation applied in the BMW-- real time light simulation*****. The journal of navigation vol.53 no.1, p.30-41. (E)**

In this paper, the authors first discuss the advantages of using Global Positioning System (GPS) for accurate navigation. The role of driver assistance systems is then discussed. The authors then introduce a new light concept known as Adaptive Light Control (ALC) which is designed to improve traffic safety at night. ALC can improve headlamp illumination by continuously adapting the headlamps according to current driving situations and environment. Results from real-time computer simulations are reported.

Manassero, G. et al. (1998). ***Adaptive headlamp: a contribution for design and development of motorway light.*** **SAE technical paper #980010. (E)**

Design and prototyping of an adaptive headlamp that is varied using actuators is presented. Beam aim is varied from 1^{o} to 0^{o} and dynamic leveling speeds were subjectively assessed for illuminance, glare, and comfort. Beam shape variability was modeled using segmented, elliptical, and 3 different parabolic reflectors; beam pattern modification was achieved by moving the source up and down along the optic axis. Elliptical reflectors were not found to be useful. The parabolic reflector gives 7^{o} of divergence for a total shift of 3.5mm and the segmented reflector gives a divergence of 4^{o} for a total shift of 2.6mm. Further consideration is required for the variation of these divergences, the corresponding illuminance values, and appropriate outer lenses.

Manassero G. and Paolini A. (1999). ***Adaptive Lighting Systems: Technical Solutions and a Methodological Approach for Photometric Specifications.*** **PAL 1999 vol. 6, p.514-525. (E)**

Adaptive lighting system architecture consisting of sensors, an electronic control unit, and actuators, is presented. Contrast sensitivity functions were obtained from road tests to make visual field maps of contrast sensitivity for country and motorway driving. A test car equipped with AFS was used to measure visual sensitivity of the driver as a function of distance and lateral position of obstacles and light beam photometry, for each of several conditions: no traffic, oncoming traffic, and incoming traffic. Contrast sensitivities for country beam at a 40m distance are plotted, for each of the three conditions. Glare from incoming traffic on right-side rearview mirror seems to be a problem. Potential AFS beam patterns are suggested.

McLaughlin, S., Hankey, J., Green, C. and Larsen, M. (2003). ***Discomfort glare ratings of swiveling HID headlamps*****. USG No. 3774. General Motors North America. (NA)**

This study evaluated glare caused by swiveling high intensity discharge (HID) headlamps compared to fixed HID headlamps. Subjects, ranging from 57 to 65 in age, rated discomfort glare of the two types of headlamps by using the deBoer scale in eight different driving approach scenarios—(1) making a large right turn (R=180m), (2) making a large left turn (R=180m), (3) making a smaller right turn (R=80m), (4) making a smaller left turn (R=80m), (5) turning left beside a participant vehicle at an intersection, (6) turning left in from of a participant vehicle, (7) turning right beside a participant vehicle, and (8) driving on a straight lane. The results suggested that swiveling headlamps provided equivalent or reduced discomfort glare in all scenarios, except for two cases: the case of the straightaway (scenario (8)), which showed no statistically significant effect, and the case of the 80m lefthand turn (scenario (4)), in which swiveling headlamps elicited poorer glare ratings. It was also found that HID headlamps are acceptable (larger than 5 on the deBoer scale), regardless of the headlamp types (swiveling or non-swiveling), in a wide range of approach scenarios.

Neumann, R. (2003). ***Advanced front lighting system with halogen bulb concept-safety improvements for everybody.*** **PAL 2003 vol. 10, p.715-722. (E)**
This paper proposed an inexpensive AFS solution using halogen headlamps instead of HID headlamps. The concept is to swivel the halogen beam to widely illuminate the roadways while driving curves. An experiment measured recognition distances of targets on a test track. The results of the experiment showed that the more difficult the target recognition became, the more effective the halogen AFS worked. The results also suggested that, with the halogen AFS, drivers could detect pedestrians 1.8m earlier than with the standard headlamp system. This paper concluded that the halogen AFS can improve visibility by 55% from standard halogen lamps, compared to 23% for HID standard and 68% for HID AFS headlamps. The halogen AFS can be 25% less expensive than the HID AFS.

Neumann, R. (2004). ***AFS halogen headlamp system: experimental study and first field results.*** **SAE technical paper #2004-01-0439. (E)**
A Visteon study evaluates AFS halogen and HID systems for seeing distance in comparison with static halogen and HID systems. Object recognition and reaction distances were measured, and these metrics were used to approximate visibility. Based on these results, AFS Xenon, AFS halogen, and static Xenon were found to increase visibility 68%, 55%, and 23% more than static halogen, respectively. The AFS halogen system will be available for 1/3 the price of its HID counterpart and still increases visibility considerably, making it a viable solution for everybody.

Port, O., and Armstrong, L. (1998). ***Your car may be smarter than you*****. Business Week vol.3584, p.85-86. (NA)**
This article describes some of the advancements in automobile technology that can make driving easier and safer. From small laser headlights for improved aerodynamics to LED tail lights for better visibility, everything is going high-tech. Silicon is displacing metal in adaptive suspensions and "by-wire" steering, acceleration, and breaking. Radar can scout for trouble ahead. Digital-imaging chips can look backward and provide a wide-angle view in the rear-view mirror, while other imagers help cars squeeze into tight parking spaces.

Rosenhahn, E.O. (1999). ***Headlamp Components for Adaptive Frontlighting— Usability of a Lighting Function for Adverse Weather Conditions.*** **PAL 1999 vol. 6, p.677-688. (E)**
Wet roads reduce visibility by increasing glare and decreasing average luminance, which decrease drivers' contrast sensitivity and increase their glare sensitivity. Glare illuminances and threshold luminances for HID and halogen headlamps in wet road conditions were measured for a range of distances. For short exposures of transient glare, adaptation level does not shift, but for long exposure times, adaptation level [as measured by re-adaptation time] is determined by glare illuminance. These findings define a goal for adverse weather headlamps to reduce exposure of oncoming drivers to transient glare. A beam distribution is designed and made that has reduced illuminance within a specific angular zone: it produces less glare for oncoming drivers while still allowing the driver to see. Glare illuminance is reduced 52% in the critical zone, loss of contrast sensitivity is estimated to decrease, and readaptation time is estimated to decrease. An interesting note: the primary factor affecting visibility is the layer of water on the windshield, which no amount of beam design will fix.

Rosenhahn, E. O. (2001). ***Adaptive Headlamp Systems Concerning Adverse Weather: Fog.*** **PAL 2001 vol. 9. (E)**
Visual range in fog is decreased by two main effects: stray light from headlamp backscatter, and exponential extinction of forward headlamp candlepower. Using a simulation program

based on the Mie theory of scattering, the important contributing factors to these two effects are identified and an adaptive fog headlamp design is proposed. The adaptive fog headlamp would have a sharp cutoff line between -1^{o} and -2^{o} and would adjust with fog density conditions. Additionally, the distribution should be asymmetric between the left and right headlamps since the left headlamp contributes more to backscatter for the driver.

Rosenhahn, E. (2002). ***Control strategies and fail-safe-concepts for adaptive lighting system.*** **SAE technical paper #2002-01-0525. (E)**

In the next few years a lot of car manufacture will offer adaptive headlamp systems as an option or as standard equipment for their products. These headlamps will provide an advantage concerning comfort and traffic safety for the driver. On the other hand, for a general acceptance of all traffic participants the level of glare has to be controlled carefully. In developing an adaptive headlamp, new techniques have to be installed in the headlamp and in combination with the electronic control unit, which analyzes various sensor information. A complex system of different lighting modules and moving optical parts will be introduced in future headlamps. The high level of complexity requires special concepts for the case of failure, which have to be fixed in the development process of the headlamp with the target of finding effective and cost saving solutions. Some main aspects of this control strategy are presented and discussed in this paper.

Rosenhahn, E.O., Hamm M. (2003). ***Motorway Light in Adaptive Lighting Systems*****. PAL 2003 vol. 10, p.868-882. (E)**

The first part of this paper evaluated motorway function of AFS by evaluating target detection of 20cm*20cm gray targets (reflectance=10%) located along the shoulder of the street. The results suggested that recognition distances of targets were 70m, 85m, 118m, and 148m for a halogen low beam, an HID low beam, a motorway beam (1) and a motorway beam (2), respectively. In the second part of this paper, 53 subjects assessed AFS functions including a town beam, a turning light beam, and a motorway beam. The average ratings suggested that most subjects were satisfied by both all functions (ratings: town light=7.5, turning light =8, motorway light =8.5 on a nine point scale with 9 being best). The subjects also compared the AFS motorway beam and a HID headlamp system with a standard halogen headlamp system. The results showed that the motorway beam was the most satisfactory system regarding comfort and safety.

Rosenhahn, E. (2003). ***Fog headlamp-visibility investigations and performance requirements for redefinition in adaptive headlamp systems*****. SAE technical paper #2003-01-0555. (E)**

Improving the range of fog headlamps in comparison to standard fog beam patterns can provide safety benefits during nighttime fog condition. Some results of investigations concerning fog beam pattern is given in this lecture and the conclusions for an improved fog beam pattern is described. In the field of future adaptive headlamp systems, further improvements can be provided by activating the fog headlamp or by adapting the beam pattern to different fog density conditions automatically. Taking into account that several sensors for the detection of the visual range are under development and automatic adaptation of the car's beam pattern to the weather condition will be possible in the future, the driver's requirements for different fog situations should be defined.

Rumar, K. (1997). ***Adaptive Illumination Systems for Motor Vehicles: Towards a More Intelligent Headlighting System.*** **Report No. UMTRI-97-7, Ann Arbor: The University of Michigan Transportation Research Institute. (NA)**

A "speculative, optimistic" report on the problem of vehicle forward lighting and suggested solutions. Current transportation lighting solutions, headlamp technologies, and adaptive systems are reviewed. Specific AFS system development efforts are mentioned: Lucas Autosensa, leveling devices, gradual dipping of the high beam, separate lighting functions and active curve lamps, and ROVELI. Based on these studies, the basic parameters of AFS direct and *indirect* (side, undercarriage, and top lights) illumination systems are laid out. This report is highly speculative and there is very little data presented to support any of the assumptions made. Political, economic, and technical obstacles to AFS integration and a prospective timeline are suggested.

Rumar, K. (2002). ***Night Vision Enhancement Systems: What Should They Do and What More Do We Need to Know?*** **Report No. UMTRI-2002-12, Ann Arbor: The University of Michigan Transportation Research Institute. (NA)**

This report is an evaluation of the current status and potential future of night vision enhancement systems. Night vision and nighttime visibility of objects of varying size and brightness is reviewed, and image-based infrared technologies are introduced: near infrared (NIR, 780-3000nm), mid infrared (MIR, 3000-6000nm), and far infrared (FIR, 6000-16000nm). NIR systems are active, with both a source and detector, whereas MIR and FIR are passive systems. Specific manufacturer prototypes incorporating NVES systems are described, and the challenges of system performance requirements are detailed. Emphasis is on the coordination of the NVES image with the real-world view. Safety potential is estimated based on detection distance increases.

Sato, T. Kojima, S., Matsuzaki, M. (2001). ***The smart headlamp system with variable low-beam pattern.*** **SAE technical paper #2001-01-0854. (J)**

1: Stanley's AFS, called "Smart Headlamp System (SHS)" was evaluated in terms of visibility and discomfort glare. Discomfort glare evaluation used Schmidt-Clausen's formula (Schmidt-Clausen and Bindels, 1974).

2: Oncoming glare of the SHS is slightly higher than conventional headlamp system but still within acceptable range.

3: Adaptation level of 1.0cd/m^2 was used based on Olson's study (Olson et al., 1990).

Schreuder, D.A. (1975). ***Vehicle lighting within built-up areas*****. Institute for Roadway Safety Research SWOV, P.O. Box 71, Deernsstraat 1, Voorburg-2119. (E)**

A "city beam" pattern was discussed based on reviewing literature from 1950s to 1974. The optimum light for the front of motor vehicles to be used on lit roads should have an intensity that is lower than present low beam headlights, but higher than present sidelights. It is suggested that the minimum luminous intensity should be at least 20cd, and the maximum not more than about 100cd. When road lighting is present (even very poor road lighting), low beam headlights an make only a small, and mostly negligible contribution to illumination and thus to the visibility of objects.

Glare from the low beam headlights of oncoming traffic disturbs perception in all normal nighttime situations. Moveable headlamps were considered as a future technique.

The upper limit of the luminous intensity, 100cd, of the "city beam" was considered based on the level of admissible glare. Relevant research results are given by: Adrian (1969, 1964, 1969); Allen (1970); Bindels (1973); De Boer & Morass (1956); Fisher (1974); Fisher & Christie (1965); Hartmann (1963); Hartmann & Moser (1968); Hemion (1968); Johansson et al. (1963); Vos (1963); Webster & Yeatman (1968); Wortman & Webster (1968).

Schwab G. (1999). ***Illuminances and Their Curves at Selected Points in Dynamic Traffic Situations.*** **PAL 1999 vol.6, p.696-707. (E)**

Photometric measurements are taken in the field at several locations in the road. Measurements are triggered by a photoelectric sensor in the vehicle's path and a time-delay. Results are compared by headlamp system type [parabolic, free-form, or HID projection], road condition [wet or dry], and lateral lane position [right, left]. Measurement results are presented statistically [frequency distributions] and it is shown that many illuminances do not fulfill legally required values, and are above or below statutory min and max values on the basis of ECE geometry. The findings allow a realistic approximation of headlamp glare intensity at the eye as a function of time.

Schwab, G., Gall D. (2003). ***Optimization of a bending beam function based on vehicle dynamics.*** **PAL 2003 vol. 10, p.998-1012. (E)**

This paper discussed performance of three swiveling headlamp systems—a parallel system, a divergent system, and a unilateral system. Experiments measured recognition distances of targets (0.2m*0.2m, reflectance=13%) using five subjects. The results suggested that, for left-hand curves, any swiveling beam systems exceeded the conventional fixed systems by more than 20m in recognition distance. In the radius range from 200m to 300m, however, there was no improvement in recognition distance by using any swiveling systems compared to the conventional fixed system. In right-hand curves, swiveling systems exceeded the conventional system only when the radius is less than 200m. In some special cases such as curve exits, however, the unilateral system scored the best performance regarding recognition distance. The second part of this paper conducted assessments comparing a conventional fixed HID headlamp system, a unilateral system, and a parallel system. The results suggested that both swiveling systems were rated three units (in the evaluation scale) better than conventional fixed HID system.

Sivak, M., et al. (1997). ***Glare and mounting height of high-beam headlamps used as daytime running lamps.*** **Lighting Res. Technol. vol.29 no.4 p.206-210. (NA)**

This analytical study examined the effects of mounting height on discomfort glare from reduced-power high-beam headlamps used as automotive daytime running lamps. Of interest were the effects for mounting heights between 0.864m (34in) and 1.372m (54in)-the range in which full-power low beams are currently allowed, but reduced-power high beams are not. Three analyses were performed. The first analysis involved estimating the illuminance reaching a preceding driver via rear view mirrors. The second analysis compared glare illuminance from reduced-power high beam with that from full-power low beam. The third analysis evaluated the expected changes in discomfort-glare ratings from reduced-power high beams as a function of increased mounting height. The analysis was based on photometric information from five high beams and 43 low beams from lamp manufactured for the United States market. They were performed for five following distances and three lateral offsets of the vehicles. The results indicated that allowing reduced-power high beams with mounting heights between 0.864m and 1372m would not appreciably increase discomfort glare for preceding drivers as compared with a)glare from reduced-power high beams at a mounting height of 0.864m, or with b) glare from currently allowed full-power low beam.

Sivak M., Flannagan M., & Miyokawa T. (1999). ***Determining the Most Effective Ways of Improving Current Headlighting*****. PAL 1999 vol.6, p.723-732. (NA)**

Illuminances from a "standard" pair of headlamps are calculated at a number of points in space. A select group of parameters are varied over a small range of values, and the most sensitive of these parameters are ranked in order of importance. Vertical aim is determined to be the most important factor in improving current static headlamp designs.

Sivak, M. et al. (2001). ***Masking of front turn signals by headlamps in combination with other front lamps*****. Lighting Res. Technol. vol.33 no.4 p.233-242. (NA)**

The visibility of a front turn signal is decreased if a headlamp is located near the turn signal. Consequently, both the US and ECE regulations require the turn signals to be more intense in such situations. However, it is unclear how adjacent light sources affect suprathreshold aspects, such as conspicuity. The present field study was designed to examine effects of several factors on the nigh-time conspicuity of front turn signals. Specifically of interest were the effects of the number, luminous intensity, and spatial arrangement (including spacing) of the potentially interfering lamps. The following are the main findings: (1) The conspicuity of a turn signal was significantly lower when it was separated from a 1000 cd low-beam headlamp by 50 mm rather than 100 mm (central-to-edge). A 200 cd turn signal at 100 mm was equal in conspicuity to a 288 cd turn signal at 50 mm. This effect is smaller than the effects obtained in previous studies using threshold-visibility paradigms. (2) Adding a second masking light source, at the same 50 mm spacing as the first masking light source, significantly influenced the conspicuity of the turn signal. The effect of the second masking source can be compensated for by an increase in the turn signal intensity corresponding to 8.5% of the intensity of the second masking source. (3) The conspicuity of the turn signal was unaffected by the spatial arrangement of two masking light sources.

Sivak, M; Flannagan, MJ; Schoettle, B; Nakata, Y. (2001). ***Benefits of applying adaptive lighting to the US and European low-beam patterns*****. HS-043 309, UMTRI-2001-20. (NA)**

This analytical study examined the potential benefits of applying two embodiments of adaptive lighting to the US and European low-beam patterns: curve lighting that involves shifting the beam horizontally into the curve, and motorway lighting that involves shifting the beam vertically upward. The curve lighting simulations paired 80-m radius left and right curves with a horizontal beam shift of 15 degrees, and 240-m radius curves with a shift of 10 degrees. The motorway lighting simulations involved upward aim shifts of 0.25 degrees and 0.5 degrees. For both curve and motorway lighting, changes in both visibility and glare illuminance were considered. Market-weighted model year 2000 US and European beam patterns were used. The authors conclude that curve lighting, as simulated here, would substantially improve seeing performance on curves for both types of beams. On left curves (but not on right curves) there would be an increase in disability glare for oncoming traffic. No major discomfort-glare problems would be expected. Although the shifted US beams were found to perform slightly better overall than the shifted European beams, the main difference in performance is between the shifted and nominally aimed beams. Motorway lighting, as simulated here, would also substantially improve seeing performance, with the benefits already present at an upward shift of 0.25 degrees. Because the increases in glare illuminance would be minor, and because motorways often incorporate median barriers or wide separations between lanes of opposing traffic, the authors do not expect substantial problems with increased glare. The European beams benefit more from this embodiment of motorway lighting than do the US beams. (This is the case because under nominal aim the European beams provide less visibility illuminance and their vertical gradient is steeper.) Nevertheless, the nominally aimed US beams tend to outperform the European beams shifted upward 0.25 degrees.

Sivak, M., Flannagan, M., Schoettle, B. and Nakata, Y. (2001). ***Quantitative comparisons of the benefits of applying adaptive headlighting to the current US and European low-beam patterns.*** **PAL 2001 vol.9, p.942-957. (also SAE technical paper #2002-01-0524). (NA)**

Glare illuminance levels (illuminance at an eye position) and visibility levels were calculated for left and right curve road conditions; European and the US beam pattern; with and without bending beams. Adaptation level was always 1 cd/m^2.

This study concluded that glare is unlikely to be a problem with the shifted beams.

Sullivan, JM; Flannagan, MJ. (1999). ***Assessing the potential benefit of adaptive headlighting using crash databases.*** **HS-042 899, UMTRI-99-21. (NA)**

This report used 11 years of data from the Fatality Analysis Reporting System (FARS 1987-1997) to investigate the sensitivity to light level in three crash scenarios in which various forms of adaptive headlighting might have safety benefits. The scenarios included fatal pedestrian crashes at intersections, on dark roads, and single-vehicle run-off-road crashes on dark, curved roads. Each scenario's sensitivity to light level was evaluated in two ways. In the first method, the seasonal pattern of crashes throughout the year was compared to the seasonal pattern of light level in three daily time periods (twilight, daylight, and nighttime), applying the same twilight-zone logic as Owens and Sivak (1993). Both of the fatal crash scenarios that involve pedestrians tracked the seasonal fluctuation in light level during this period, showing a decline in crashes during the twilight periods in the spring and summer, and an increase in crashes during the fall and winter. The daylight and nighttime control periods, in which light level is fixed, showed no similar trend. In contrast, the single-vehicle run-off-road scenario failed to show any influence of light level, and seems to be significantly associated with alcohol use. In the second method, the number of fatal crashes was compared across the changes to and from daylight savings time, within time periods in which an abrupt change in light level occurs relative to official clock time. Once again, scenarios involving pedestrians were most sensitive to light level, while single-vehicle run-off-road crashes showed little effect of light level. The results suggest that adaptive lighting may produce the greatest measurable safety benefit when it addresses the problem of pedestrian vulnerability in darkness.

Sullivan, J., Flannagan, M. and Schoettle, B. (2002). ***The appearance of bending beam from other vehicles.*** **Report No. UMTRI-2002-2. (NA)**

One of the most promising proposals for an Advanced Front Lighting System (AFS) is bending beam, in which light from headlamps is directed into the path of a turn. A field study was performed to investigate the appearance of bending beam, implemented as a swiveling beam pattern, to other roadway users. Observers were asked to view a series of turning maneuvers performed by a vehicle equipped with bending beam and were asked to comment on the maneuvers in three sets of trials. The three sets were structured to direct progressively more of the observer's attention to the vehicle's front lighting system. Responses were classified to indicate the degree to which observers spontaneously noticed specific details about the front lighting system. In another series of trials, observers viewed turning maneuvers in which the bending-light function was inactive on half of the trials, and were asked to distinguish whether it was active or inactive. Results suggest that observers are not very sensitive to the movement of bending beam and often report lamp movement as variation in the intensity of the lamp; that is, the lamp appears to brighten and dim. Although the appearance of variation in brightness could be used as a signature for bending beam, observers demonstrate a limited ability to distinguish bending beam from fixed light. Overall, the results suggest that the likelihood that beam movement would either help or hinder other road users is small.

Von Hoffmann, A. (2001). ***Analysis of adaptive light distributions with AFSim.*** **PAL 2001 vol.9, p.1018-1029. (E)**

Glare illuminances from oncoming AFS headlights with different cutoff angles were measured for the purposes of developing computer software, called AFSim, for use in assessing AFS design performance. Measurements were taken for wet and dry road conditions, for straight and curved roadways. The contribution of glare from reflected the road, in dry conditions, increases with the AFS systems, but this is not significant for distances <30m. In wet conditions, the glare is increased by AFS systems for distances <125m, but reduced for distances >125m. In none of these cases is the effect relevant for practical driving situations. The measurements used gas discharge lamps. As compared with conventional systems, bending beam functions result in more glare on wet left curves and less glare on wet right curves. The adverse weather function can significantly reduce this effect.

Von Hoffmann A., Gall D. (2003). ***Criteria for the development of adaptive light distributions considering dry and wet road surfaces*****. PAL vol.10, p.1169-1179. (E)**

This paper discussed the swiveling light as well as the adverse weather light function of AFS. In order to determine criteria to design these AFS functions, laboratory measurements of reflective properties of road samples and field measurements on a test ground were conducted. A rating experiment with 60 test persons under dry and wet road conditions suggested that a divergent swiveling headlamp system caused less glare to oncoming drivers on wet roadway surfaces than a parallel swiveling system.

Wada, K., Miyazawa, K., Yagi, S., Takahashi, K. and Shibata, H. (1989). ***Steerable forward lighting system.*** **SAE technical paper #980682. (J)**

This paper introduces a lamp system that will change illuminated area in response to steering angle; the prototype changes the range by moving only the sub-reflector incorporated in the lamp unit driven by an actuator. A steering angle sensor and a controller for real-time actuator angle calculation are part of the system. Beam steering is continuous: the beam angle for a headlamp can be turned 30^{o} left or right if the steering wheel turns more than 15^{o} in that direction. The system was evaluated positively in a righthand drive car, and an eye-tracking sensor showed that road illumination matched the driver's line of sight.

Watanabe, T., Nakamura, N. and Matsumura, N. (2001). ***The research on the effectiveness of AFS bending lamp in Japanese road environment.*** **PAL 2001 vol.9, p.1042-1053. (J)**

This is a Japanese AFS study which finds that with AFS headlamps, the eye fixation point moved closer to the daytime fixation point than to the nighttime standard fixation point. Subjective ratings of target visibility from 5 subjects also increased for AFS.

Westermann, Hanno. (2002). ***AFS history and scientific backup: Eureka project #1403.*** **GRE 48 Informal document no.30, April 2002. (E)**

This document describes the origination and basis for the Eureka project, and the industry collaborators. Phase I included marketing surveys and a feasibility study. In phase II research objectives were defined and lighting project targets developed. Applications that were identified as having specific lighting requirements included motorway, country and town roads, curved roads and cornering, and adverse weather such as fog, precipitation, and wet roads. Special overhead sign lighting was also developed, but then deemed unnecessary since modern retroreflective signs are adequately visible with a spread light of 100cd. In Phase III these investigations were converted into draft regulations that were later approved and transmitted to GRE in January 2002. Background research on glare (effect of lateral distance, visibility of pedestrians, luminous area, alignment, and dry vs. wet), vehicle dynamics, street lighting, vehicle appearance, and headlamp photometry which led to the following documents

- TRANS/WP.29/GRE/2002/18 and 19: a new AFS regulation
- TRANS/WP.29/GRE/2002/20: amendment to ECE reg.48 for AFS systems

is summarized in this paper.

- Glare: based on subjective glare appraisals, the glare intensity in zone III should not exceed 625 cd @25m. Due to differences in lateral separation distances, disability glare is increased by a factor of 30 on European motorways and 110 in the US; discomfort glare is increased by a factor of 2.1 in Europe and 2.75 in the US.
- Pedestrian visibility: to improve the chance of seeing a pedestrian, object illuminance should be at least 3.6 lx and 8 lx for a 50% and 90% chance of detection, respectively. This translates to 8lx@25m in point E50R/L (5000cd) and 16lx @25m in point E75R (10000cd) on the measuring screen for each headlamp.
- Wet roads: Wet roads do not greatly affect discomfort glare but the lower adaptation luminances does increase glare sensitivity. Calculations show that the influence of reflections, which increases foreground illumination, exceeds that of direct light on discomfort glare.
- Vehicle dynamics: vehicle inclination is extremely sensitive to tilt changes caused by passengers, trunk loading, road unevenness, and acceleration. Tilt can change as much as 2^{o}, affecting cutoff, which makes a dynamic headlamp leveling system highly recommendable.
- Photometry: all of the findings discussed in the paper are used to suggest headlamp photometry requirements for the various zones.
- Appearance: differences in headlamp size and shape were found to have no effect on appearance as long as the intensity ratio between left and right does not exceed a factor of 10. For asymmetric headlamp assemblies, the distance between right and left should be at least 400mm to maintain accustomed vehicle appearance.

Worner B. (1999). ***Adaptive Frontlighting— Experimental System Development and Functional Evaluation.*** **PAL 1999 vol. 6, p.844-853. (E)**

For AFS application in town conditions, which are characterized by lower speeds and public lighting, the conventional light distribution can be dimmed and reduced in the symmetrical part, or, depending on speed and ambient light conditions, a very wide illumination only can be chosen which does not interfere with the contrast provided by public illumination. It was found that dimmed lighting for public lit areas was fully sufficient and the conspicuity to other traffic participants was quite good.

An experimental system of variable headlamps is designed and evaluated. The design consisted of a main module with fixed distribution that can be dimmed, with two movable shutters; fixed side illumination modules; two “spot” modules for right and left curbs. 9 possible beam patterns are plotted. After a 6 month evaluation, the system was found to be useful by drivers, and oncoming drivers [meetings pre-arranged] were objection-free. Illumination level limitations were therefore found to be tolerable.

Yamamoto, I. (2004). ***AFS light distribution control.*** **SAE technical paper #2004-01-0438. (J)**

Two bending beam systems were studied: one that swivels above the cutoff and one that swivels below, both using HID lamps. An eye fixation point of 3s into the future determines where to aim the AFS illumination. It is determined that swiveling both headlamps, but at different angles, is best for improving illumination at the fixation point. Calculations show that glare for oncoming drivers using these conditions is still under ECE regulation, 2 lx.

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